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RANKINE'S THERMODYNAMICS.

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III.

Communications received since the publication of my lecture in the last May and June numbers of this Magazine, offer a reason for making the following additions. It would add to the interest of the discussion if other writers would present their views or make criticisms upon what has been said in a public manner; but, as I stated at the outset, that I was not self-satisfied with that work, I the more readily comment upon the subject matter suggested by private communications, as they may be of service to others who are studying the subject. One asks "how does $\frac{Q}{dQ}=\frac{\tau}{d\tau}$? Rankine seems to make

$$\frac{M}{\delta M}=\frac{Q}{\delta Q}=\frac{\tau}{\delta\tau}.$$

Are all the $\delta\tau$'s equal for equal quantities of heat absorbed?" The latter part of this question seems to imply a misconception of Rankine's definition of Q and τ. Neither measures the heat *absorbed*. They refer only to *sensible* heat, or *actual* heat. A substance while absorbing heat m y not only do external work, but also internal work, and all the heat thus absorbed that does *work* is no more heat, and the remainder of the heat absorbed remains as heat—it is sensible heat, and is represented by Q, and, being proportioned to the temperature, is, for a given mass of a substance, also represented by τ, the absolute temperature. All the $d\tau$'s are not equal for equal quantities of heat *absorbed*, but all the $d\tau$'s are equal for equal increments of *sensible* heat, thus, if 10 units of heat be absorbed by a pound of a substance, and 5 units be consumed in changing the molecular constitution—as, for instance, changing the state of aggregation, similar to that of changing ice to water, or water to steam, then only 5 units remain as heat, and Q would not be 10 but 5. Again, if a homogeneous substance whose mass is M containing the quantity Q of sensible heat, be divided into an indefinite number of parts, each being δM, the quantity of heat will be divided in like manner, and hence each portion, δM, will contain a quantity δQ of the heat.

$$\therefore \frac{Q}{M}=\frac{\delta Q}{\delta M}$$

The temperature will not be divided in the same manner, for each δQ will be of the same temperature as Q, the temperature simply measuring the *intensity* of the heat and not the quantity. But if we conceive the sensible heat, δQ, of one of the small masses to be composed of an indefinite number of small parts, and each of these to be measured by an increment of temperature, $\delta\tau$, so

that the entire temperature of δQ will be τ, then, since the temperature of each δQ will be τ the temperature Q will also be τ. This idea may be illustrated by means of rectangles; thus let EFGH, Fig. 25, represent the mass M of the sub-

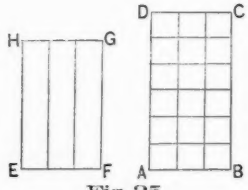

Fig. 25

stance, and ABCD the quantity of heat Q. Then if these rectangles be divided into the same number of equal vertical strips, one of the strips in EG may be represented by δM, and in AC by δQ; and we at once have

$$\frac{Q}{M}=\frac{\delta Q}{\delta M}.$$

Let a scale of temperatures from absolute zero be represented by the line AD, and let this be divided into equal parts, then will horizontal lines through these points divide AC or Q into the same number of equal parts, each of which will be $\delta' Q$. If τ be the temperature, one of the divisions of τ will be $\delta\tau$, so that we have

$$\frac{Q}{\tau}=\frac{\delta' Q}{\delta\tau}$$

If, however, the *number* of divisions of AC into horizontal strips be the same as those of the vertical strips, then will $\delta' Q=\delta Q$, and hence

$$\frac{Q}{\tau}=\frac{\delta Q}{\delta\tau},$$

and this is always possible, for we may begin with τ, making $\tau\div\delta\tau=n=$the number of divisions, and then divide Q the other way making $\delta Q=Q\div n$, and $\delta M=M\div n$; thus we have:

$$\frac{M}{\delta M}=\frac{Q}{\delta Q}=\frac{\tau}{\delta\tau}=n.$$

To illustrate further. In Fig. 26, in passing from the state A to the state B, the heat *absorbed* has been shown to be represented in foot-pounds by the indefinitely extended area MABN. This is not the Q above used. Q may be the *sensible* heat in the body in the state A, capable of doing the external work MAv_1x, and the internal work maAM by an indefinite expansion without transmis-

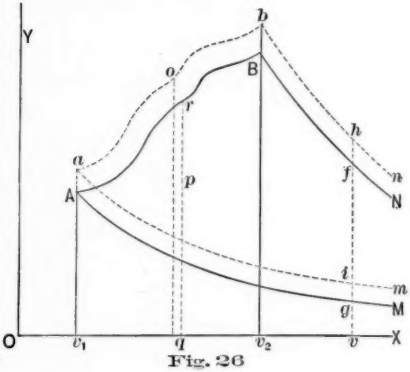

Fig. 26

sion of heat. In the discussion of this case on pages 424 and 425, a term was dropped, and thus the reasoning was apparently vitiated; and we here restate the case as it should have been. In Fig. 26 we have *nbam* equal to the heat absorbed in doing both external and internal work in passing from the state A to the state B; and if H_a be the sensible heat at state A, and H_b that at state B; then

$$nbv_2X+bv_2v_1a-mav_1X=nbam$$

or
$$\begin{aligned} H_b+bv_2v_1a-H_a &= mbam \\ &= nbBN+NBv_2X+baAB \\ &\quad +Bv_2v_1A-maAM-MAv_1X \\ &= MABN, \end{aligned}$$

since

$$nbBN+baAB-maAM=0,$$

or
$$S_b+S-S_a=0. \qquad (p_1v)$$

But the heat in the body in foot-pounds in the state B *plus* the work, both external and internal, done in passing from the state A to state B, *minus* the heat, in foot-pounds, in the state A must be the heat absorbed; hence MABN is the heat absorbed in passing from A to B. But

$$bv_2v_1a=v_1ABv_2+baAB$$
$$=\int pdv+S$$

$$= \int p dv + S_a - S_b ;$$

$$\therefore \text{MABN} - \int p dv = H_b - H_a - S_b + S_a$$

which should be substituted for equation (*n*), page 425.

How does it appear that the *expression* of the Second Law includes both external and internal work, as Rankine claims; and how does it appear that the total work may be deduced from that of the external? In attempting to explain these more fully, we can scarcely do better than amplify what Rankine has done, although we will give different methods.

In Fig. 27 let the substance whose initial volume is Ov_1 at the pressure v_1A and temperature τ, expand isothermally at the temperature τ to the volume Ov_2 and pressure v_2B; external work will be done, represented by $v_1\ v_2$ BA, and internal work represented by AB*ba* let AM and BN be adiabatics proper to the substance through A and B respectively, then, as has been shown, will this indefinitely extended area MABN represent the total heat absorbed in passing from the state A to state B, and since the temperature has been maintained constant by a supply of heat from an external source, the intrinsic energy of the substance remains constant, and hence will be the same at the state B as at A, and hence all the heat absorbed has been transmuted into work of some kind, whether it be external or partly external and partly internal. Hence, the area MABN in terms of heat units expressed in foot-pounds must give the entire work which the heat absorbed

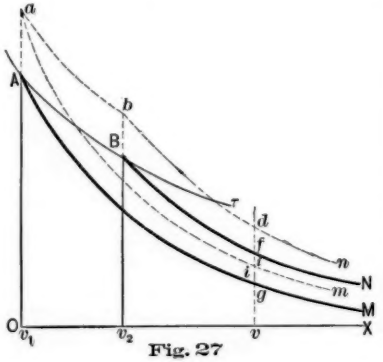

Fig. 27

at constant temperature does. We therefore seek an expression for this area.

In Fig. 28 conceive isothermals *fh*, *ji*, etc., drawn across the area between the adiabatics AM and BN, representing succesive equal decrements of temperature, then will the successive strips thus formed be equal. For, after the substance has expanded from A to B isothermally, let it expand without transmission of heat along the adiabatic BN, the process being arrested when the temperature τ has fallen an amount $\triangle\tau$, at which the pressure may be represented by the ordinate of *a* above OX; then compressing the substance isothermally to *f* and adiabatically to A. In this process heat represented by MABN has been absorbed, and M*fh*N rejected, and since the substance has been worked in a complete cycle, the resultant work is all external, the resultant internal work being zero. Beginning again at A, passing to B, thence adiabatically until the temperature has fallen $2\triangle\tau$ at which the pressure will be the ordinate of *i*, thence isothermally to *j*, thence adiabatically to A. The same heat MABN has been absorbed in this as in the former case, but only M*ji*N has been rejected, and twice as much has been transmuted into external work as before. But twice the heat when worked in such a cycle with any substance will do twice the external work, at least within the limits of the errors of observation. We will give a mere outline of the reason. Sir William Thomson proposed an "absolute thermometric scale" in which equal quantities of work done

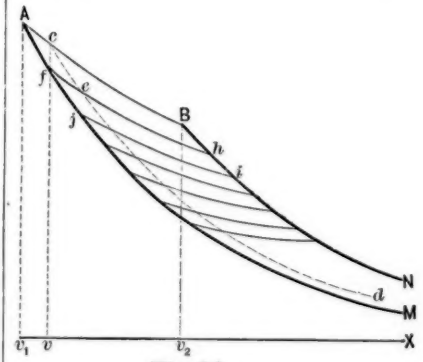

Fig. 28

by heat as the agent in a reversible engine should correspond to equal divisions on a scale, and that the scale thus formed should be considered a scale of temperatures; * but it was afterwards found that the equal divisions of an air thermometer, within the range used in practice, agree with the "absolute scale" within the limits of the errors of observation, so that the latter is substituted for the former, and by reversing the statement of Thomson, we may now say that a given mass of any substance worked according to Carnot's cycle through the same range of temperature as measured by an air thermometer on any part of its scale, will produce the same amount of *external* work. For practical purposes the mercurial thermometer may be considered as coinciding with the air thermometer,† so that, when we are expressing a general idea, without attempting to express the refinements of the science, we may say that when work is done by heat according to Carnot's cycle the differences between the highest and lowest temperatures through which the substance is worked, measured according to a standard mercurial thermometer, are proportional to the respective works done, or

$$t' - t'' : t_1 - t_2 :: w' : w_1$$

or in our own case

$$\triangle\tau : 2\triangle\tau :: w : 2w.$$

or generally

$$\triangle\tau : m.\triangle\tau :: w : m.w.$$

If now the divisions, $\triangle\tau$, which we have assumed are commensurable with τ, the temperature of AB, we would find the area of MABN by multiplying the area of ABhf by the number of divisions. The question of commensurability will be removed by making $\triangle\tau$ indefinitely small, and equal to $d\tau$, in which case the number of divisions will be $\frac{\tau}{d\tau}$. To find the area of ABhf, we first find the area of AcefA, where ce is an adiabatic through c and c is indefinitely near A, so that the horizontal distance between A and c will be $dv = v_1 v$.

Representing the area Acef on an enlarged scale, as in Fig. 29, prolong ef to v_1A at x, then will Ax represent the fall in pressure at the volume v_1 due to a fall of temperature $d\tau$, hence the *rate of change* of the pressure will be $\frac{dp}{d\tau}$ and for a change of temperature $d\tau$ we have

$$\text{A}x = \frac{dp}{d\tau} d\tau.$$

The area of Acef will *ultimately* equal the rectangle Aczx, for they are between the same parallels Ac and xe; but the area of Aczx will be Ax multiplied by the perpendicular between Ax and cz or dv; hence

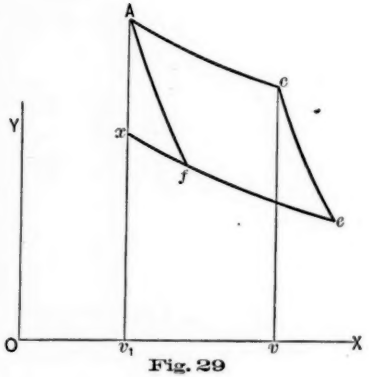

Fig. 29

$$Area\ \text{A}czx = \frac{dp}{d\tau} d\tau dv$$

since each of the elementary areas between AM and cd Fig. 28, formed in the manner above described, are equal to each other, the number being $\frac{\tau}{d\tau}$, we have

$$\text{Area MA}cd = \frac{\tau}{d\tau} \cdot \frac{dp}{d\tau} d\tau dv = \tau \frac{dp}{d\tau} dv \qquad (qz)$$

which was sought.

The area MABN may be considered as the sum of an indefinite number of strips, Ah, fi, etc., in which case the total area will be the area of AB$hf \times \frac{\tau}{d\tau}$, or

$$\frac{\tau}{d\tau} \int \frac{dp}{d\tau} d\tau dv = \tau \int \frac{dp}{d\tau} dv,$$

or the sum of areas like MAcd, in which case the area will be the integral of equation (qz) in reference to v between the limits v_2 and v_1; or

* Math. and Phys. Papers, Vol. I., pp. 393-395.
† Rankin's "Steam Engine," p. 234.

Area MABN=

$$\int \tau \frac{dp}{d\tau} dv = \tau \int_{v_1}^{v_2} \left\{ \left(\frac{dp}{d\tau}\right)_{v \text{ const.}} \right\}_{\tau \text{ const.}} dv \quad (rz)$$

which, as already stated, must be the total work done. The value of $\left(\frac{dp}{d\tau}\right)_v$ is to be obtained from the equation of the gas. Thus for a perfect gas, we have

$$\frac{pv}{p_0 v_0} = \frac{\tau}{\tau_0}, \text{ or } pv = R\tau;$$

$$\therefore \left(\frac{dp}{d\tau}\right)_v = \frac{R}{v} = \frac{p}{\tau}.$$

For imperfect gases we have in some cases, like carbonic acid gas,

$$pv = R\tau - \frac{a}{\tau v};$$

$$\therefore \left(\frac{dp}{d\tau}\right)_v = \frac{R}{v} + \frac{a}{\tau^2 v^2} \quad (r_1 z)$$

$$= p + \frac{2a}{\tau^2 v^2}$$

for which case the area MA*cd* will be

$$\tau \frac{dp}{d\tau} = \left(R\frac{\tau}{v} + \frac{a}{\tau^2 v^2}\right) dv$$

which may readily be integrated for τ constant, giving the area MABN for this case.

An element of the external work $v_1 v_2$ BA, Fig. 27, will be

$$du = p dv,$$

in which v being an independent variable does not admit of a second differential, and differentiating regarding p as a function of τ, we have

$$\frac{d(du)}{d\tau} = \frac{dp}{d\tau} dv$$

$$\therefore \tau \frac{d(du)}{d\tau} = \tau \frac{dp}{d\tau} dv \quad (sz)$$

the second number of which is the same as the last number of equation (qz).

The integral of equation (sz) is

$$\tau \frac{dU}{d\tau} = \tau \int \frac{dp}{d\tau} dv = W \quad (tz)$$

the second member of which is the same as equation (rz), and the first member is τ times the rate of doing work per unit of absolute temperature; hence the total work, W, both external and internal, during an isothermal expansion, is τ times the rate of doing external work per unit of temperature.

In the last expression,

$$dU = d\int_{v_1}^{v_2} p dv.$$

The integral of the differential of a quantity differs from the quantity by a constant; thus

$$\int d(x^3) = \int 3x^2 dx = x^3 + c.$$

But the differential of the integral of a quantity is the quantity itself; thus

$$d\int (3x^2 dx) = d(x^3 + c) = 3x^2 dx.$$

Rankine's method, pp. 308, 309, of "Steam Engine" of establishing equation (rz) is substantially as follows:—

$$\frac{\text{Area ABhf}}{\text{Area MABN}} = \frac{d\tau}{\tau}, \text{ also } = \frac{\int \frac{dp}{d\tau} dv\, d\tau}{\text{Area MABN}};$$

$$\therefore \text{Area MABN} = \tau \int \frac{dp}{d\tau} dv$$

Thomson's first solution consisted in first proving that the ratio of the limiting area A*cef*, Fig. 28, to that of the whole heat supplied was constant for all substances at the same temperature. Thus if M be the rate of supplying heat per unit of volume in order to maintain a constant temperature, then

$$\frac{\frac{dp}{d\tau} d\tau dv}{M dv} = \text{constant for } \tau \text{ constant},$$

then if μ be a function of the temperature only, we have

$$\frac{dp}{d\tau} dv = \mu M dv$$

Thomson has given to μ the title "Carnot's Function" (Math. and Phys. Papers Vol. I., pp. 187, 188, and pp. 129-134). Thomson remarks that μ "may vary with the temperature in a manner that can only be determined by experiment" (*ibd.* p. 187), but after finding that

$$\mu = \frac{J}{\frac{1}{E} + t} = \frac{J}{\tau} \text{ approximately,}$$

ibd. p. 389, a form suggested by Joule in 1828, *ibd.* p. 199, where τ is the temperature above absolute zero, resulting from

extending any one of the ordinary scales whose fixed points are the temperature of melting ice and of boiling water, downward a distance below the point of melting ice equal to the reciprocal of the coefficient of expansion of atmospheric air, he proposed an absolute scale according to which the above equality should be exact, defining temperature as the reciprocal of Carnot's function (*ibd.* p. 393). Thomson's and Joule's experiments showed that the air thermometer differed so slightly from that of an ideally perfect gas, that it may be substituted for the latter, and $\frac{J}{\tau}$ for such a thermometer becomes practically accurate; hence substituting this value of μ above gives

$$JM.dv=\tau\frac{dp}{d\tau}dv.$$

Thomson's method is followed, substantially, by Tait in his Sketch of the History of Thermodynamics, and by Stewart in his work on Heat.

Next, consider the case in which more heat is absorbed during expansion than is necessary for maintaining a constant temperature, so that while expanding from v_1 to v_2, Fig. 30, the external pressures will be limited by the curve AceB. From the state A let the expansion be isothermal from A to *b*, then will the heat absorbed be represented by the area between A*b* and the adiabatics AM and and bm_1, as just shown, and the total work done will be

$$\tau\int_{v_1}\frac{dp}{d\tau}dv$$

At *b* let the volume be maintained constant, while the pressure is increased from $v'b$ to $v'c$, an amount equal *bc*, by the absorption of heat. Since no external work is done during this operation, the energy represented by the area m_1bcm_3, between the adiabatics and *bc*,

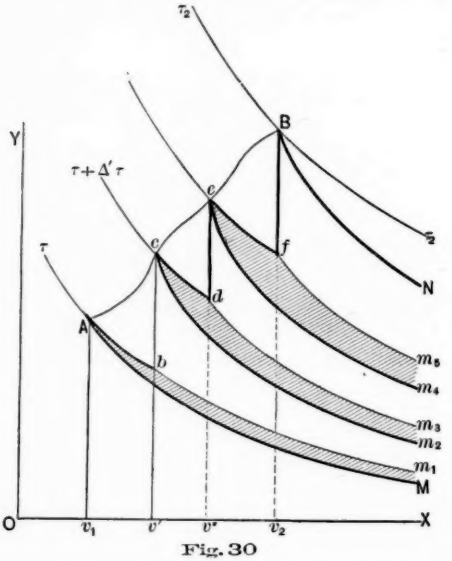

Fig. 30

will exist in the substance in the form of heat energy, and if no internal work be done this area will represent the heat absorbed. No internal work will be done if the specific heat of the substance be uniform between the limits of the temperature at *b* and *c*, as in the case of perfect gases; for which the increase of pressure *bc* will be proportional to the increase of temperature. Thus, if we have

$$pv=R\tau,$$

then

$$dp=Cd\tau, \qquad (uz)$$

when *v* is constant, and C equal to R÷*v*.

According to the dynamic theory of heat, the essential energy in the body—or that which makes it hot after abstracting all work—varies directly as the absolute temperature, and for which the specific heat for a constant state of aggregation for a particular body is constant. Let k be this specific heat, called by Rankine "the *real* dynamic specific heat," then for an increase of temperature $\Delta'\tau$, the stored actual energy will be

$$k.\Delta'\tau = m_1 bcm_2. \qquad (vz)$$

If the gas be not perfect, the pressure will not increase directly as the temperature, and the departure from the gaseous law will be due to internal work for an increase of temperature at constant volume; for which case the area m_1bcm_2 will not represent the heat *absorbed* in raising the pressure from b to c, and, generally more heat will be absorbed than thus represented, but, at the same time this area will represent the entire *external* work which the substance can do by an indefinite expansion on account of the heat imparted from state b to state c. There appears to be no space within the figure NBAM for representing the *internal* work due to changes of temperature only, for it is already covered by figures representing work done and intrinsic energy imparted to the substance; but since the internal work is at the expense of heat absorbed, it may be represented by a strip somewhat similar to those shown in the figure. If it could be known how far the substance must be expanded beyond b at the constant temperature τ in order that the area between adiabatics would equal the internal work done in raising the temperature from that at the state b to that at the state c, the value of such work would be the integral of $\tau\frac{dp}{d\tau}dv$ between the proper limits for v. But we are unable thus to find it, and equally unable to determine a height on the prolongation of bc such that the area between two adiabatics drawn through the extremities of such a line will equal the required amount of heat so lost. Rankine's method is equivalent to considering the required value as an area, one side of which, at least, is bounded by an isothermal indefinitely extended. Thus, since $\tau\frac{dp}{d\tau}$ may be considered as equivalent to an ordinate eq. (rz), so its differential, or $\tau\frac{d^2p}{d\tau^2}d\tau$ may be considered as the increase of this ordinate due to an elementary change of temperature in the equation of the gas, and $= pq$, Fig. 31. Then will the entire area $c\mathrm{CD}d$ for a change $d\tau$ be

$$\left\{\tau\int_{\infty}^{v_1}\left(\frac{d^2p}{d\tau^2}\right)_v dv\right\}d\tau \qquad (wz)$$

It is plain from this treatment that equation (wz) will not give the loss of heat due to internal work at constant volume for finite changes of temperature, since for such a case τ is variable while in (wz) τ in the brackets is constant, but as it is known to be small compared with the value of k it is assumed to be constant and in all ordinary cases entirely neglected.

It may be better to consider the area $c\mathrm{CD}d$, Fig. 31, as representing the heat destroyed by internal work for a change of one degree of temperature, on the supposition that the change is uniform for that degree, in which case its value will be expressed by the quantity within the $\{\ \}$ in expression (wz), and that quantity will be the rate of change per degree of temperature, and then for the change $d\tau$ the amount of heat destroyed by internal work at constant volume will be the value of the entire expression of (wz) as before.

This mode of treatment by the author is not satisfactory to the writer. It is true that the heat destroyed by internal work may be represented by an area, but its true value is not represented by an area bounded by an isothermal. If the heat destroyed would have raised the pressure an amount equal to $c\mathrm{D}$, Fig. 31, if the

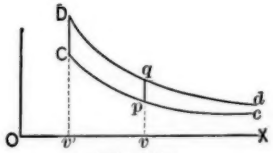

Fig. 31

substance had the same specific heat at that state and were a perfect gas, then would the area representing this heat be that between two adiabitacs through C

and D, like the area m_1bcm_2, Fig. 30. In order to expand the substance along an isothermal *c*C, heat must be supplied continually, so that if the analysis by which expression (*wz*) was established were correct, it would seem that the expression would give a value in excess of the heat destroyed; and if this were so it could the more safely be neglected in the equation for heat absorbed, since its value is small according to the author's analysis. We are not in doubt as to the author's intended treatment of the integral of this expression, since he has made a numerical reduction of expression (*wz*) for carbonic acid gas (*Trans. of the Royal Society of Edinburgh, Vol. XX.*), from which it appears that this expression is treated in a manner quite similiar to that of the fundamental one, $\tau\frac{dp}{d\tau}dv$; that is, τ is heated as constant, $\frac{dp}{d\tau}$ is differentiated regarding v as constant, giving $\frac{d^2p}{d\tau^2}d\tau$, and $\frac{d^2p}{d\tau^2}dv$ is integrated as if τ in the value of $\frac{d^2p}{d\tau^2}$ were constant. Using the equation for carbonic gas, we find by differentiating equation (*r*, *z*), considering v as constant, as we should,

$$\frac{d^2p}{d\tau^2}=-\frac{2a}{\tau^3v^2};$$

$$\therefore\ \tau\frac{d^2p}{d\tau^2}=-\frac{2a}{\tau^2v^2}$$

which, according to our understanding of Rankine, is the ordinate *qp*, Fig. 31, and, being negative, may be considered as operating against an increase of the pressure as it really does. Considering τ as constant, and multiplying by dv, we have for the integral of the expression

$$-\frac{2a}{\tau^2}\int_{\infty}^{u}\frac{dv}{v^2}=\frac{2a}{\tau^2v}$$

as already given in equation (*gz*), page 480. A numerical reduction of this quantity, for particular values of τ and v is given on page 480 of the last June number of this Journal, and is precisely similar in form to that given by Rankine in the *Transactions* above refered to; and the value thus found is treated as constant during the integration in reference to $d\tau$ in expression (*wz*). Thus far the treatment is precisely similiar to that of the expression $\tau\int_{v}^{v'}\frac{dp}{d\tau}dv$ except that in the last expression the limits of integration are finite, while in the former, one of the limits is infinite. This exception is, at least, suggestive. The area considered is not a narrow strip just above A*b*, Fig. 30, limited by the ordinates v_1A and $v'b$, and it should not be, for such a strip would be due to an increase of the *observed* value of τ, making it $\tau+d\tau$, and the area of such a strip would be

$$(\tau+d\tau)\int_{v_1}^{v'}\frac{dp}{d\tau}dv-\tau\int_{v_1}^{v'}\frac{dp}{d\tau}dv$$

$$=d\tau\int\frac{dp}{d\tau}dv=\int\frac{dp}{d\tau}\,dv\,d\tau,$$

as originally found.

Then, too, this work is not done during the expansion from v_1 to v' but at the fixed volume v'. The area considered by the author is one of indefinite extent, as indicated by the limits.

We analyze this term as follows: In Fig. 27, at the volume v_2 and temperature τ the external pressure is $v_2\mathrm{B}=p$, and the virtual pressure resulting from internal work during the isothermal expansion is

$$v_2\mathrm{B}=\tau\frac{dp}{d\tau},$$

when $\frac{dp}{d\tau}$ may be obtained by an experiment upon the gas, or found from its equation, and τ is simply the observed absolute temperature; hence

$$\mathrm{B}b=\tau\frac{dp}{d\tau}-p,$$

is a virtual pressure doing internal work under an isothermal expansion. If now there be a change of temperature, p as well as τ will change, and $\frac{dp}{d\tau}$ necessarily change, and for an infinitesimal change of temperature, the virtual increase in the ordinate representing internal work will be the differential of B*b*, or

$$d\tau\frac{dp}{d\tau}+\tau\frac{d^2p}{d\tau^2}d\tau-\frac{dp}{d\tau}d\tau=\tau\frac{d^2p}{d\tau^2}d\tau$$

which is of the same form as before obtained, but in this case τ has been considered variable, while in the former case it was considered constant. This differ-

ence is of little or no importance in considering the state B, but is vital in what follows. As before stated, we do not yet know how much heat must be absorbed, under the conditions imposed, in order to produce an increase of the ordinate equal to $\tau\frac{d^2p}{d\tau^2}$ at B; but considering that the adiabatic BN is a function of p and v only, and hence is a fixed line for any given substance, we may conceive that another line is drawn near it, passing through a point at a distance $\tau\frac{d^2p}{d\tau^2}$ above B; then will the imaginary strip between these two lines be the required area. (Or, if preferred, conceive that the strip is just above bn.) Let p_2, v, be the co-ordinates of any point in the adiabatic BN, then will the vertical distance between BN and the imaginary line above described, be

$$\tau\left(\frac{d^2p_2}{d\tau^2}\right),$$

where τ is the temperature at the point considered; and the area of the entire imaginary strip will be

$$\int_{v_2}^{\infty}\tau\frac{d^2p}{d\tau^2}dv,$$

in which the order of the limits will be reversed if the above gives a negative value. Or, the order of the limits may be changed and a minus sign placed before the expression. Another way of considering the order of the signs and limits is given on page 482.

It appears from the last expression that the co-efficient of v will depend upon τ, unless $\tau\frac{d^2p}{d\tau^2}$ is independent of τ, which is not the case with any known gas except for sensibly perfect gases when that term reduces to zero; and since τ cannot, generally, be expressed as a function of v the expression cannot be integrated with τ a variable. But knowing from experiment that the specific heat of the more perfect gases, such as air and carbonic acid, are nearly uniform—and these are the only ones especially considered by the author in discussing this term, page 317 of his text—the term $\tau\frac{d^2p}{d\tau^2}$ will be small in all practical cases, and hence the imaginary area, above considered, will depend for its value chiefly upon the function of v, so, as an *approximation*, we consider τ constant; after which we may proceed as our author has done. In this way we find the approximate value of expression (wz) for a finite change of temperature. The value of the change of the specific heat at constant volume due to changes in the temperature is determined by direct experiment, rather than by the above analysis in which the fundamental equations are themselves more or less empirical. Still $\frac{d^2p}{d\tau^2}$ and $\frac{d^2v}{d\tau^2}$ represent the deviation of the laws of actual gases and other fluids from the ideal condition of a perfect gas, at least qualitatively if not strictly quantitatively.

At c, Fig. 30, let work be done by expansion at constant temperature to d, thence at constant volume heat absorbed raising the pressure an amount de, and temperature an amount $\Delta''\tau$; thence to f and finally to B, where the temperature is τ_2. The shaded part represents heat absorbed and work done at constant temperature, and the unshaded strips the heat absorbed which remains in the substance as heat, and which is capable of doing external work, while the heat absorbed doing internal work at constant volume under a change of temperature is not shown in the figure. It thus appears that the entire heat absorbed by a substance may be considered in two parts:—1st, *as doing work entirely by isothermal expansion*, and, 2d, *as producing a change of energy*.

Adding the several quantities, we have for the total heat *absorbed* during the expansion from v_1 to v_2 and of pressure from v_1A to v_2B,

$$\mathrm{H}=_{a,b}\left\{\begin{array}{l} k.\Delta'\tau+k.\Delta''\tau+\quad\ldots \\ \tau+\int_{\infty}^{v_1}\frac{d^2p}{d\tau^2}dv.\Delta'\tau+ \\ (\tau+\Delta'\tau)\int_{\infty}^{v'}\frac{d^2p}{d\tau^2}dv.\Delta''\tau+ \\ \quad\ldots\ldots\ldots \\ +\tau\int_{v_1}^{v'}\frac{dp}{d\tau}dv+ \\ \quad(\tau+\Delta'\tau)\int_{v'}^{v''}\frac{dp}{d\tau}dv+,\ \&c. \end{array}\right\} \quad (xz)$$

Conceive the number of sides of the inscribed polygon $Abcdef\ldots$ increased in-

definitely, the vertices falling on the line AceB, then

$$k.\Delta'\tau + k.\Delta''\tau + \&c. = \int k d\tau = k(\tau_2 - \tau_1)$$

and, considering the coefficients of $\Delta'\tau$, $\Delta''\tau$, &c., in the second and third line as equal to each other, and equal to P,

$$\Sigma\left\{\left(\tau + \Delta\tau\right)\int\frac{d^2p}{d\tau^2}dv.d\tau\right\} =$$

$$\int_{\tau_1}^{\tau_2} \mathrm{P}\,d\tau = \mathrm{P}\left(\tau_2 - \tau_1\right),$$

and the sum of the quantities in the third line is the total work, both external and internal, done at the successive differential isothermal expansions. The external work being represented by $\int pdv$, and the internal by S', equation (xz) becomes

$$\underset{a,b}{\mathrm{H}} = \left(k + \mathrm{P}\right)\left(\tau_2 - \tau_1\right) + \int_{v_1}^{v_2} pdv + \mathrm{S}' \quad (yz)$$

mal expansion, and heat supplied at constant volume.

This is the case just considered and is shown in Fig. 30.

b. Let work be done under an isothermal expansion and heat abstracted at constant volume.

In this case the final temperature will be less than the initial, or τ_2 be less than τ_1, and the first term of equation (yz) will be negative.

This case is shown in Fig. 32, when $\mathrm{MA}bm_1$, m_2cdm_3 represent heat *supplied* during isothermal expansion and m_1bcm_2, $m_3d\mathrm{B}m_4$, heat *abstracted* at constant volume.

c. Let work be done under an isothermal compression and heat abstracted at constant volume.

In this case heat must be abstracted during the compression, and the case will be illustrated by Fig. 30, if the substance

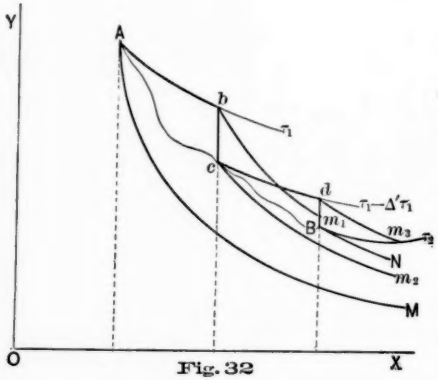

Fig. 32

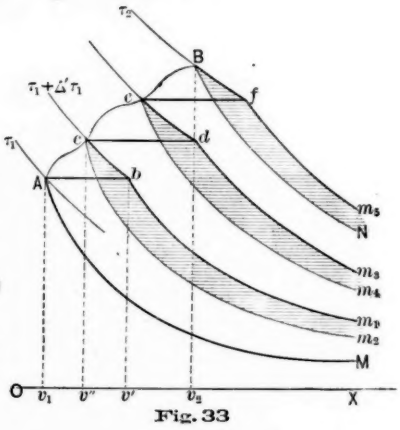

Fig. 33

Letting S be the entire internal work done due both to change of temperature and to isothermal expansion, equation (p_1z), then

$$\mathrm{S} = \mathrm{S}' + \mathrm{P}\left(\tau_2 - \tau_1\right) = \mathrm{S}_a - \mathrm{S}_b$$

and the preceding equation becomes

$$\underset{a,b}{\mathrm{H}} = k\left(\tau_2 - \tau_1\right) + \int_{v_1}^{v_2} pdv - \mathrm{S}_b + \mathrm{S}_a$$

which is Rankine's equation (2), page 313.

Several cases arise under this equation, of which we consider the following:

a. Let work be done under an isothermal expansion and heat supplied at constant volume.

This is the case just considered and is shown in Fig. 30.

b. Let work be done under an isothermal expansion and heat abstracted at constant volume.

In this case the final temperature will be less than the initial, or τ_2 be less than τ_1, and the first term of equation (yz) will be negative.

This case is shown in Fig. 32, when $\mathrm{MA}bm_1$, m_2cdm_3 represent heat *supplied* during isothermal expansion and m_1bcm_2, $m_3d\mathrm{B}m_4$, heat *abstracted* at constant volume.

c. Let work be done under an isothermal compression and heat abstracted at constant volume.

In this case heat must be abstracted during the compression, and the case will be illustrated by Fig. 30, if the substance be worked from the state B to that of the state A. Work is here done upon the substance throughout the entire operation.

d. Let work be done under an isothermal compression and heat supplied at constant volume.

This case is illustrated by Fig. 32, where the substance is worked from the state B to that of A, and τ_2 considered as the initial and τ_1 as the final temperatures. Here work is done on the substance isothermally, and hence heat is abstracted during this operation; but energy is im-

parted to the substance by the absorption of heat at constant volume.

This graphical solution may be applied directly to Article 148 of the author, in which τ rnd p are made the independent variables, instead of τ and v as in the preceding solution. In Fig. 33, let Ov_1 be the volume of a pound of the substance, AB, the locus of the pressures and volumes as before, and which for brevity is called the "path of the fluid." At A let expansion be made at constant pressure, then will the path of the fluid be a horizontal line Ab, and the heat supplied will be represented by the area MAbm_1 indefinitely extended, AM and bm_1 being adiabatics. If k_p be the heat

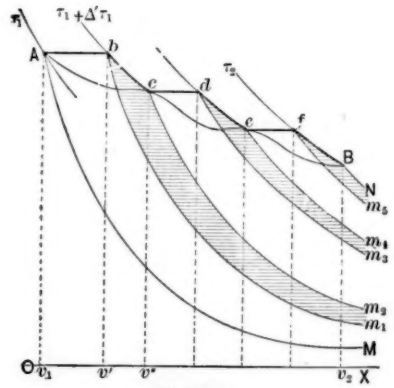

Fig. 34

necessary to increase the temperature of a pound of the substance one degree at constant pressure, and $\Delta'\tau$ the increase of temperature in expanding from v_1 to v', then will the heat represented by MAbm_1 be

$$\Delta'\tau \cdot k_p$$

if we neglect, as we will now do, the internal work due to the change of volume at constant pressure. At b let the substance be compressed isothermally until its path bc intersects the path AB at c, then will the heat *abstracted* during this operation be represented by m_1bcm_2 indefinitely extended and equals

$$\left(\tau + \Delta'\tau\right)\int_{v''}^{v'} \frac{dp}{d\tau} dv$$

as has been shown in the preceding investigation. The heat absorbed, therefore, in passing from A to c along the paths Ab and bc, will be

$$\Delta'\tau \cdot k_p - \left(\tau + \Delta'\tau\right)\int_{v''}^{v'} \frac{dp}{d\tau} dv$$

and so on to B.

It is advisable, however, to consider, for the general case, one in which the given conditions operate in the same sense; we therefore pass to the case in which heat is absorbed during both operations as shown in Fig. 34, in which the area MAbm_1 represents the heat absorbed at constant pressure, m_1bcm_2 heat absorbed at constant temperature, and so on. Hence the total heat absorbed in passing in this way from state A to that of state B will be

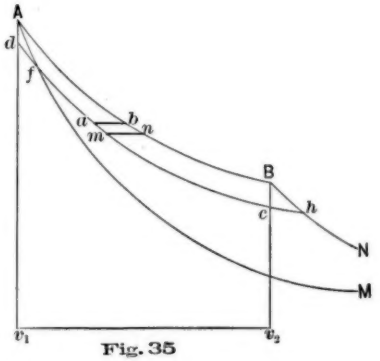

Fig. 35

$$H = k_p \cdot \Delta'\tau + k_p \cdot \Delta''\tau + \&c. \ldots$$

$$+ \left(\tau + \Delta'\tau\right)\int \frac{dp}{d\tau} dv + \ldots \tau_2 \int \frac{dp}{d\tau} dv$$

and passing to the limit, the heat absorbed when the path of the fluid is AcB will be

$$H = k_p \left(\tau_2 - \tau_1\right) + \Sigma_{v_2}^{v_1} \tau \frac{dp}{d\tau} dv \qquad (2,2)$$

It remains to change the independent variable from v to p in the last term of this equation. Let the area MABN, Fig. 28, which is the same for this case as in the former one, be divided as before by isothermals differing by the constant quantity, $d\tau$, the number of spaces or strips will be $\tau \div d\tau$ as before, and we proceed to find the area of the upper strip ABhf. The value of dv in this case is not arbitrary, but is made to depend upon the temperature. To show its value graphically, let AB and fh, Fig. 35,

represent two consecutive isothermals, then, since $\frac{dv}{d\tau}$ is to be independent of the pressure, any horizontal line, as *ab*, limited by the isothermals, will be *dv*, and will be written $\frac{dv}{d\tau}d\tau$. The depth of an elementary parallelogram *abcd* will be arbitrary and equal *dp*; hence

$$\text{area } abcd=\frac{dv}{d\tau}d\tau dp.$$

Ultimately, the area AB*hf* will equal A*Bcd*, and we have

$$area\ \text{AB}hf=\int_{p_1}^{p_2}\frac{dv}{d\tau}d\tau dp$$

$$=-\int_{p_2}^{p_1}\frac{dv}{d\tau}d\tau dp$$

and the area

$$\text{MABN}=-\frac{\tau}{d\tau}\int_{p_2}^{p_1}\frac{dv}{d\tau}d\tau dp$$

$$=-\tau\int_{p_2}^{p_1}\frac{dv}{d\tau}dp$$

which, substituted in equation (z_1z), gives

$$\text{H}=k_p\left(\tau_2-\tau_1\right)-\tau\int_{p_2}^{p_1}\frac{dv}{d\tau}dp$$

which is the author's equation (1) of article (248). The author writes zero for the inferior limit of *p*, which value represents an indefinite expansion, but as isothermal expansion is necessarily finite, and as an infinite isothermal expansion demands an infinite amount of heat, doing also an infinite amount of work, both limits should be finite. The author, in his applications, uses finite limits, as on pages 319 (lower part), 322, 323, 349, 387, 397 and other places. The zero limit for *p* is, unfortunately, used on pages 314, 315, 319, 328, where a finite value is advisable, and in practical cases is absolutely necessary, and the same remark applies to the infinite limit in equation (1), page 319. To show the effect of using these limits, take the case of a perfect gas, when we have:

$$pv=\text{R}\tau,$$

$$\therefore\ \frac{dp}{d\tau}=\frac{\text{R}}{v},$$

and hence

$$\int_{\infty}^{v}\frac{dp}{d\tau}dv=\text{R}\int_{\infty}^{v}\frac{dv}{v}=\text{R}\left(\log.\ v\right)_{\infty}^{v}$$

$$=\text{R}\ (\log.\ v-\infty)=-\infty$$

and similarly for the expressions $\int_{o}^{p}\frac{dv}{d\tau}dp$ and $\int_{o}^{\tau}\frac{d\tau}{v}$. These points are mentioned because they are liable to perplex a student not already familiar with the subject. The infinite limit for *v* is correctly used on pages 312, 313 and 316, as we have shown in these articles, and the zero limit for *p* on page 317; but these expressions refer to different areas than the preceding.

The fact that the specific heat at constant pressure exceeds that at constant volume for sensibly perfect gases, may also be illustrated graphically. Thus, in Fig. 36, let $\tau_1\tau_1$ and $\tau_2\tau_2$ be two isother-

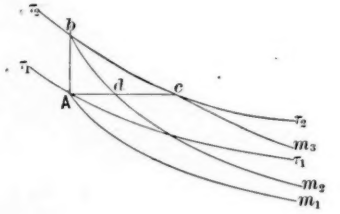

Fig. 36

mals differing by one degree. At any point *a* of $\tau_1\tau_1$ draw the vertical *ab* and the horizontal *ac*, and through *a*, *b* and *c* draw adiabatics, then will m_1abm_2 represent the specific heat at constant volume, and m_1acm_2 the specific heat at constant pressure, but since the adiabatics slope downwards more rapidly than the isothermals, the adiabatic bm_2 will intersect *ac* in some point as *d*; hence m_1acm_2 exceeds m_1abm_2. Since writing the above I find that Rankine has used a figure similar to Fig. 36 for determining the ratio of the apparent specific heats (*Phil. Trans. Roy. Soc.*, 1854).

We here state the two laws of thermodynamics in language as nearly parallel as we are able, that their distinctive characteristics may be the more quickly seen.

First Law.—Mechanical energy and heat energy are mutually convertible, the

transfer being made in any manner, at the rate of J foot-pounds *per British thermal unit* (J being Joule's equivalent).

SECOND LAW.—Mechanical energy and heat energy are mutually convertible, for a change in the volume of the working substance at the *rate* of $\tau\frac{dp}{d\tau}$ *per unit of the change of volume.*

The symbolic expression of the first law may be as follows: Let T be the number of thermal units transferred to one pound of the working substance (or abstracted from it), N the number of pounds of the working substance, and W the entire work done by the substance on account of the heat absorbed (or done upon the substance in producing heat), then

$$W=J\,.\,NT.$$

But the value of T can be found from this equation only when the entire work W is external. If it be partly internal, the entire work, both external and internal, must be determined by the symbolic expression of the second law, which is, considering that the *rate* may constantly vary,

$$dW=dv\,.\,\tau\frac{dp}{d\tau};$$

$$\therefore\ W=\tau\int\frac{dp}{d\tau}dv.$$

The two laws of thermodynamics may be likened to the two divisions of Mechanics, Statics and Dynamics.

On page 306 of the author's text is the statement: "It is required to find how much of this work is performed by the disappearance of heat," and on page 428 of the last May number of this magazine, reasons are given for canceling the words "of this." But the sentence may mean, "it is required to find how much of this work is performed by the disappearance *of an element* of heat"; for the heat represented by Aϵ, Figs. 28 and 29, is an infinitesimal of the heat which disappears during the performance of the work $A\upsilon=pdv=U$, and since, in Fig. 29, Aϵ ultimately equals ϖc, we have

$$acef=d(A\upsilon)=d^2U=dpdv.$$

But p is a function of the actual heat Q, and hence the expression is properly written,

$$\frac{d^2U}{dQ}dQ=\frac{dp}{dQ}dQdv.$$

It should be observed that the heat disappearing is not δQ, as some have inferred, but it is the difference between the heats for two different isothermal expansions, one being at the constant heat Q, the other at the constant heat $Q+\delta Q$, the amount of the expansions being dv in both cases. In Fig. 28, Mfcd is the amount disappearing at the constant heat.

Q and MAcd at the heat $Q+\delta Q$, for the expansion dv, and the difference, or

$$Acef=\frac{d(dU)}{dQ}dQdv$$

is the heat disappearing for an element of the work dU, as before shown.

PROPOSAL FOR AN AMERICAN ACADEMY OF ENGINEERING.

BY WILLIAM KENT, M.E.

Read at the Buffalo Meeting of the American Association for the Advancement of Science, Aug. 20, 1886.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

Do we need another engineering society? Are not the various American societies, the Civil Engineers, Mining Engineers, Mechanical Engineers, Sanitary Engineers, Electrical Engineers, the Engineers of the Army and of the Navy, the various local societies in Boston, Philadelphia, Pittsburgh, Cleveland, Chicago, St. Louis and other places, and last, but not least, the section of Mechanical Science and Engineering of the American Association enough? What reason is there for the existence of another society?

In 1871 a similar question might have been asked, when only one of the above

named societies was in existence, the American Society of Civil Engineers. What reason, then, for the organization of a new society, the Institute of Mining Engineers? But in that year a small group of men organized that society, and it now numbers over 1,400 members. In 1880 another group of men organized the American Society of Mechanical Engineers, and it now numbers 700 members. All of the other societies above mentioned are also, I believe, well and flourishing. In 1882 I attended a meeting of this section at Montreal, when there were only half a dozen members present. We have no need to-day to ask whether this section is flourishing. As far as I know, all the engineering societies are doing excellent work, and nobly fulfilling the objects of their existence, which objects are, chiefly, to give opportunities for the members of each society to get acquainted, to mutually diffuse information among themselves, and so to increase the knowledge of all, and to increase the already formidable bulk of American engineering literature. So important are these objects that many engineers find it beneficial to join three or four different societies, and to spend a great deal of time and money attending their meetings.

But with all due respect for all the societies above named, not one of them, nor all together can do the work which I think another society, formed on a different model, ought to do for the benefit of the engineering profession. I think the time has now come when we should have another society formed in a different way from any now in existence, and with a different object. My scheme is an ambitious one; parts of it, if not the whole, may be Utopian, but the idea has been growing in my mind for at least two years, getting larger and larger, until I think it is time to unburden myself of it and let some one pull it to pieces if it deserves it, or give form and comeliness to the rough structure as it leaves my hands, if worthy of such treatment.

I look far into the future and I see a society or Academy of Engineering which shall not be strong in numbers—not over 300 or 400, but powerful in influence for good, whose members comprise army and navy engineers, civil, mining, metallurgical, mechanical, electrical, and sanitary engineers, and are all distinguished men in their respective branches, having *done* something creditable in the engineering line as a pre-requisite to membership. Such membership is the highest honor that can be conferred by the profession upon an American engineer, except that of officership in the same academy, and it is an honor that can be conferred only through merit which is appreciated by the majority of the profession, and not through personal favoritism of a nominating committee. It is an honor, moreover, which cannot be withheld from a deserving man by a blackball of one, or seven, or even fifty members. It is an aristocracy based upon intellect and achievement, and yet a democracy in which all are equal, in which majorities rule and minorities are represented, in which each member is a representative of a branch society of lower degree and owes allegiance to it.

In such a society the army engineer could lose his *caste*, and no longer look down on the civil engineer, for both he and the civil engineer would be promoted to a higher caste; yet the army engineer would still be a member of the Army Engineers' society, and the civil engineer a member of the Civil Engineers' society.

With such an academy in existence, the head of the bureau of engineering of the navy, with a political naval advisory board, would not concentrate in themselves all the knowledge necessary to build ships of war, for each would find in the academy other men better posted in shipbuilding than themselves, and would call them in for consultation. The Secretary of the Navy would not need to make a servile copy from the drawings of a Japanese man-of-war, for he would find in the academy men who would design a better one. There would be no necessity for a council of engineering societies to organize and agitate for the public works of the Government to be carried on according to the laws of common sense, for the Committee on Public Works of the academy would be charged by the Government to report what works should be undertaken, and members of the academy, some of them army, some navy, some civil, some mechanical engineers, according to the character of the work in hand, would be in responsible charge of them. The honorable member of Congress in whose dis-

trict is Cheesequake creek, would not log-roll an appropriation for digging out that famous stream, in exchange for a vote in favor of a similar appropriation for some unheard of stream in Minnesota, for Congress would appropriate a round sum to be expended for river improvements under the direction of the academy.

The army engineers would not condemn a system of harbor improvement because it was proposed by a civilian, for army and civil engineers would all be friends together in the academy. A mixed civilian and army and navy board would not be appointed to conduct iron and steel tests, and be given an appropriation one year and then be disbanded the next, for the academy would have in charge a series of tests which would run on steadily for ten or twenty years, with an endowment or appropriation sufficient for the work.

I see the academy meeting once a year, one year in Boston, the next in San Francisco, the next in New Orleans, and so on. A whole week is given to business, papers are read and discussed, but they are papers of national importance. They are scrutinized before being printed, and printed before being read. There is no rubbish amongst them. Committees are appointed to carry on investigations, and appropriations are made for their expenses. One committee is instructed to go to Europe and report on sewage and water pollution; another is to report on ordnance and armor for ships of war; another on reclamation of waste lands, irrigation and forestry; another is to conduct experiments on cylinder condensation of engines; another to redetermine the laws of flow of fluids in pipes; another to experiment with the fuels of the United States, and the best methods of burning them; another is to take up and continue the unfinished work of the late lamented U. S. Iron and Steel Board. A medal is presented to one of the members for a distinguished achievement in engineering, an appropriation is made to one of the members to enable him to complete a costly original investigation. A prize is offered for the best paper on a certain subject, and another for an invention which is considered to be of the greatest benefit to mankind.

The academy is rich. It owns a large fire-proof building in New York City, in which there is the most complete engineering library in the world, and also a museum of models, plans and photographs of important engineering works; a working laboratory of research for the use of the research committees of the academy and others who may be entitled to it; and a hall for meetings which is used by the Civil, Mining, Mechanical and other engineering societies when they meet in New York City.

The academy is interested in the education of the engineers of the future. There is an engineering college with a large endowment, in which all branches of engineering are taught, and according to the terms of the endowment one portion of its board of trustees is elected by the academy, and a committee of the academy is intrusted with the allotment of some of its fellowships and scholarships.

The academy is not a venerable body of fossils and old fogies, for it is constantly being enriched by new blood from the several American societies. It is the foremost body of engineers in the world, and the leading engineers of Europe are proud to be admitted to its membership, as the highest honor the engineering profession has to offer them.

Is such a dream impossible of realization? I think not. Three things are necessary for its fulfillment.

1st. The men.

2d. The organization of these men.

3d. The money.

The men we have. Some are in the army, some in the navy, some in one society and some in another, but they are not all acquainted with each other; they are scattered over the wide country and never meet together. Glance down the list of names of the Civil and Mining Engineers societies, and we see names of men of national reputation and great ability who might be shining lights in a congress of societies, but who also, from their very attachment to the one society of their choice, are strangers to all the others. What a company these distinguished men would make if they could be organized into one body.

The money would be forthcoming if such a body of men were organized. Scarcely a year passes but some millionaire leaves a large sum of money to found some college, hospital, library, art

gallery, manual training school, or other institution of public benefit. The American Association has received sums of money to hold in trust for the prosecution of original research. What better disposition of his money could a millionaire make than to endow the American Academy of Engineering with a trust fund to be applied to its several objects, the founding of a library, a museum of engineering, a laboratory for original research, or a scholarship fund for engineering students? Suppose the academy established and in possession of a working laboratory, would not the national and State Governments be calling upon it frequently for research into questions affecting the public health or safety? and these calls would necessarily be accompanied by liberal appropriations. Of course this matter of money would be one of slow growth. The academy would be poor at first, existing on the fees and contributions of its own members, but money would flow to it as soon as it showed that it had the right men to use the money, and the right kind of organization.

So we have the men and can get the money.

How can we get the organization?

My suggestion, which can no doubt be improved upon, is as follows:

Let the question be agitated in the three American societies, the civil, the mining and the mechanical engineers, and let them appoint a committee of conference to draw up a plan of organization of the academy.

I would suggest to the committee of conference this scheme:

The original members of the academy to be the presidents and past presidents of all the engineering societies of the United States. These men to meet and incorporate the academy. After its nucleus is thus formed it is to grow by accretions of members from the American societies as follows:

Five members to be chosen each year from each of the large societies, the civil, mining and mechanical engineers, and two each from the army engineers, the navy engineers, the sanitary engineers and the electrical engineers, making twenty-three new members to be added each year. The method of selecting these members is the following:

Each active member of each society chooses from the whole list of members of his own society, of not less than five years' standing, a number of names equal to the number to be elected from his society; thus a member of the civil engineers' society chooses five names, and a member of the sanitary engineers' society two names. These he writes upon a ballot which he transmits to the secretary of his own society. Tellers are appointed who select from all the names voted upon those having the highest number of votes, the ten highest from the civil, mining and mechanical engineers' societies, and the four highest from each of the others. The lists of these selected names are then certified to the secretary of the academy, who prints them in a ballot list, each name having opposite it the number of votes it received in its own society. The members of the academy then vote upon these names by scratching out one half of those nominated by each society. Tellers of the academy are appointed to count these ballots and certify as elected those receiving the highest number of votes, the five highest of those nominated by each of the large societies, and the two highest from each of the others. Members elected to the academy have thus to pass through two ordeals; first, they must be among the members receiving the highest number of votes in their own society for the nomination, and second, they must be among those receiving the highest number of votes of the members of the academy. There is thus no nominating committee, no council passing upon nominations in secret conclave, and no blackball.

The above is the outline of the scheme. All I ask for it is a vigorous discussion.

HYDROGEN IN GLOW LAMPS.—The well-known fact that the carbon filament of a vacuum glow lamp is gradually dissipated by some electric or thermal effect of the vacuum, points to the trial of lamps, in which the vacuum is discarded and its place supplied by an atmosphere of hydrogen, nitrogen, or other gas, which cannot oxidise or burn the filament. Messrs. Siemens Brothers have lately been making lamps filled with hydrogen and they find that these lamps do not become sooty on the inner surface of the glass. Next to a filament, which will remain incandescent in the open air, an envelope which will remain clean and not of itself destroy the filament is a desideratum.

THE NATION'S GREAT PROBLEM.

By R. H. THURSTON, Director of Sibley College, Cornell University.

An Address delivered at Rose Polytechnic Institute, Terre Haute, Indiana, June 23, 1886.

To the student of history, past and contemporaneous, a wonderful panorama is presented by biologists, and by the historians, of the progress of the race, from those primeval times of which the records are only written in the rocks, and of which the story is only told us by the geologists—from those days which were ushered in by the command. "Let there be light"—up to the days of steam, electricity, and the common school. And in this historical retrospect nothing can be more interesting, nothing can be more suggestive and striking, and nothing can be more seriously impressive, than the continuous succession of mighty social upheavals and revolutions that have made that progress so strangely intermittent, and so apparently defiant of all law as to forbid all attempt at prophecy of the nearest future. Nations rise and nations fall; progression is followed by retrogression; civilization advances great peoples to a high standard of life, in all the arts, and in every field of intelligence, only to yield, later, as a broken reed, and to let Greece, or Rome, or the empire of the Saracens, sink back into barbarism. India once flourished, and is now like dry leaves; Egypt grew as a great banyan grows in the groves of her predecessor; and Egypt falls into decay, hollow in every root, every trunk, and every branch. Italy dominates the earth, and Italy is conquered by the Goths and the Vandals who spread the dark mantle of savagery over her decaying body, and yet transplant the seeds of light to their own homes, where, later, it enlightens the world.

The history of every nation is thus marked by tremendous social changes, sometimes resulting in advancement, sometimes in retrogression, even where the people on the whole, gain in wealth, intelligence, and moral standing. France, best of all, illustrates this proposition, and Great Britain has a history which is almost as remarkable, and is quite as instructive. The people of England, France and Germany have gained in all that makes life worth living, in the material sense as well as intellectually, and yet only through a progress that has been hardly less intermittent than that of the race as a whole. Our own country had its birth in the throes of revolution. In its short life it has already experienced one mighty struggle, the result of which seemed, at more than one time during the strife, likely to be a reversal of the wheels of progress. It is thought, by more than one keen observer of our recent and our present position, that we are at the beginning of, or perhaps in the midst of, a struggle more momentous than any that has preceded.

In every one of these great revolutions, whether accompanied by war or wholly peaceful, whether the strife of nations, the revolution of a people against oppression, or the hardly less trying struggles of a nation of workers during periods of industrial depression or of actual famine, the nations suffer. Hundreds, thousands, sometimes millions, of people struggle for life, and for their children's lives, while the weeks, months, or years, of trial continue; and once they are over, go on contentedly and unthinking, through the succeeding periods of comparative peace and comfort, and into the next period of suffering, apparently without an effort to discover the cause of their misfortunes, or to find a remedy. The great movements of the world go on, continuously and irresistibly, and they are continually being caught in the mechanism of the universe, and bruised and crushed with never a thought of the possibility of escape.

As the globe on which we live, launched into space and whirling steadily on through its vast and endless orbit, with a speed exceeding many times that of the fastest shot from the most powerful modern ordnance, moves ever onward, with an energy that never weakens, and a motion that never slackens, carrying its living freight through the viewless regions of unmeasured space, regardless of any thought, wish, or effort of theirs; so the

race itself launched into life, endowed with an unmeasured and in unmeasurable energy, which carries it on through time with never-ceasing progress, must seemingly ever move forward; but, unlike the suns and their attendant planets, its movement is never unresisted. Its motion is more like that of a flowing stream, vexed by eddies, continually turned from its course by obstructions that it cannot force aside, checked by frictions that never cease, impeded by rocks and shoals that constantly compel it to change its course, to flow faster and shallower here, and deeper and slower there, and often to reverse its direction, turning for the time quite away from its final destination. But its motion cannot cease, nor can it ever turn absolutely and permanently away from its destiny. Vexed or unvexed, it must flow on into eternity.

And here is the Nation's Great Problem: How can humanity, compelled to its course toward the destiny lying away beyond sight or ken in eternity, relieve itself from the vexations of its life? How can progress be made as smooth as it is inevitable? How can the revolutions, the periods of darkness, the time of distress, be avoided? How can the seemingly unnecessary sufferings of weak and unfortunate human beings be relieved? How can progress be made steady and smooth, and easy and fruitful of good to all? How may the wise and the good and the fortunate best aid the less intelligent and evil disposed, the bad and the unfortunate, who suffer because of the perturbations of the world, the spiritual and the material, and how help to prevent those perturbations?

The wisest and best of men have found but one answer to these questions, one solution of the great problem—"Educate the people!" Educate the world in all wisdom. Teach the people a knowledge of as much of the moral and the physical law of the universe as they have capacity to absorb. Teach them that, since they cannot control the laws of nature, they must study to make those laws their servants; and, if they cannot breast the tide, they must make it the means of advancement toward the ends appropriate to their purposes. Teach them to foresee, and to prepare for, the dark days that must some time surely come. Teach them the laws that govern all social and industrial movements; that they may turn the workings of those laws to their own best and real advantage. Give the race moral education, intellectual education, manual education. Prepare them for life in a world in which no one can prosper who does not move on with it, and who does not adapt himself to its ways, and his movements to its progress; in which those who stop, or attempt to move at a lesser speed, inevitably fall.

Civilization is foresight and foreknowledge; the highest civilization is that which sees and best prepares for the remotest future.

What, then, is education? Paley says that "Education, in the most comprehensive sense of the word, may comprehend every preparation that is made in our youth for the sequel of our lives." Education is all of that, and it is more than that. It is coming to be seen to be every preparation made in our youth for the sequel of our lives, and for the rendering of the lives of those about us and those who succeed us more prosperous and more happy. It is the preparation which we are continually striving to make for successfully meeting the greater events of national life, tending to impede or to destroy national growth and progress, no less than for happily passing through individual existence.

The primary object of education is, evidently, to make the individual intelligent, self-reliant, earnest, capable; to give him the means of acquiring such knowledge as is most essential to his success in life, and to prepare him to make the most of such opportunities and advantages as may come to him, to fit him to enjoy life in the highest and best ways, and to help his neighbor to enjoy it with him. It should make him a good, useful, and reliable citizen. It should start him into the path leading into his life's work with such an outfit as should best fit him to pursue that path with most perfect success. Beyond this, it should make him a good citizen in the sense that he should be capable of doing his share in the labor of making the law helpful to the nation at large, and to all other good citizens. It should help him to foresee the future and to provide for it, not only for himself and his own family, but for the nation of which he is a member. It should aid him to make the course of its

history smooth and free from revolutions, industrial crises, or struggles of class with class, whether such strife be within the law or against the law; whether bloody or bloodless. It should so instruct the citizen that the national life may flow on, as a stream through fertile plains, unvexed and unchecked, smoothly, steadily, deep and full, and productive of all good to all men, helping all, harming none, flowing deeper, stronger, more smoothly, through all the centuries.

Our definition of education has been growing through all the past ages, to a more and more definite ideal. We speak of the old and the new; but there is no old and no new; it is all the development of that which is to come. Education, like all other great phenomena of the world, and of the universe, is undergoing evolution constantly, tending continually toward the best for our time, and for the time that is coming. Beginning with the crude ideas of the earlier civilizations, it has been steadily changing—at first speculative, next intellectually gymnastic, later scientific in every division, including not only the physical sciences, but, recently, involving the training of every human faculty, not excepting the bodily senses and organs. Our methods of education have been constantly changing to meet the continually growing and improving ideal. In the days of Aristotle, of Plato, of Socrates, men learn by following the thoughts of other men into region of philosophy far removed from the common events of life; and, in the literature of Greece and Rome, we still present to the student, to-day, the speculative side of education. With the birth of Galileo, the times of Newton, of Gilbert, of Bacon, came the study of the great phenomena of nature, and the reduction of her newly discovered laws to the systematic form which we now recognize as science. With the introduction of scientific methods of study of natural law, of the phenomena of nature, of the sciences thus given shape, came the application of this new form of knowledge to the purposes of common life, and the fruitage of the seed sowed, even in the days of Aristotle, in those first rude attempts at the construction of natural science. The later period saw these departments of human knowledge included in the accepted systems of general education. Finally, the introduction of science, and of applied science, into the schools led to the appreciation, on the part of educators, of the now universally-admitted truth that education not only may, but should, be a means of aiding men in their endeavors to make living easier and more productive of benefit in every-day work and life. Ruskin's three talismans of natural existence—labor, law, courage—are seen to assume our understanding that it shall be intelligent labor, civil law as accessory to the physical and moral laws of the universe and its Creator, and courage to maintain one's own, and his neighbor's privileges and rights—the right being kindly and generously gauged by the law and by the community. Education must now teach this definition.

The gradual evolution of methods and processes in education, as in all cases of social evolution of ideas and intellectual methods, has been a process of broadening and deepening, a process of development that has, as is invariably the case in all such developments, retained the best and the essential of the old, while seizing upon and incorporating the new. The new educations include the old; the new systems are the spine and the marrow of the old, with added stature and increased powers and grasp, with superfluous and "remanent" members and nerve and muscle pruned away, while the essential members are enlarged and strengthened and made more facile and useful. The old standpoint from which the object of education was defined was that of the intellectual gymnasts; the latest standpoint is that of the student of history and of humanity, who recognizes the fact that the "sound mind in a sound body," "the soul of a sage in the body of an athlete," such as Agassiz was said to illustrate, has its use, as well as its ornamental office, and who sees that the greatest good of the greatest number, and the greatest good of the individual as well, are to be secured by the cultivation of the powers of mind and body, with a view to making both of service, in the highest possible degree, to the individual, by helping him to work, however humble, in his place in the world, and to the nation by making its individual citizens capable as well as intelligent. We are to make the most of the man, or

woman, that mind and body, as given by the Creator, are equal to, and then to see that the mind and body, so rendered most fit to occupy the place in the world for which they are intended, get into that place and do the work allotted to them most efficiently; whether that work be delving in the soil or the chanting of a hymn; whether it be spinning or weaving, or fighting for country or freedom, or preaching or praying, making a steam engine or building a house, directing an "industrial army," in the construction of great public works, or making the laws of a nation.

As I have elsewhere remarked, it is a common saying among the wisest and most thoughtful of our wise and thoughtful fellow-citizens that the great safeguard against all such dangers as seem now to threaten our country, and I might add, against the social convulsions that have at intervals rent every form of society, and led to strife and revolutions in every nation known to history, and which have so often interrupted the progress of civilization, is the education of the people. But what is a real education of a people? What is a true education? Is it not the teaching, and especially the training, of the young with a definite understanding of the purposes for which this life is to be lived, and in such a way that they may best accomplish these purposes? Is it not such a method of instruction as shall render them wiser and of better judgment, more skillful and readier in self-adaptation to all the demands that may be made upon them, in the work of a lifetime, in the pursuit, first, of the necessaries, next, of the comforts and blessings, and, finally, of the highest gifts and purest pleasures that life can give, each in order of necessity? It is certainly not the highest education of the few that mainly concerns us, important as that phase of education undoubtedly is, not only to the few, but to the many; but it is the education of the many *well*, that is to say, their education most perfectly, with a view to the use to be made of education by them. The people must be carefully educated with a view to the people's work in life, not so educating them that they cannot strive and struggle with fate, and conquer her, and fight their way onward and upward, to the extreme reach of their powers, we may hope; but, at least, so that they may find themselves well prepared for the work which will certainly be theirs to do at the first, and for the great majority of them the work to which they must buckle themselves through life.

We are to stimulate and cultivate intelligence in the people, in every citizen, offering the best prizes and the greatest opportunities to those who are best prepared to take advantage of them and of the chances coming to them. Education, the best and most fruitful education, must be given to our people, wisely, carefully, persistently, if we would escape the terrible dangers to our nation and to our government which we so often see looming up in the near future, and presaged by a thousand threatening clouds of misrule and lawlessness. The most selfish policy unites with the most noble form of philanthropy to urge us to look bravely and determinedly upon every sign of the possibly gathering storm and adopt promptly and courageously every precaution against it.

Says Emerson, in his "Perpetual Forces":

"As cloud on cloud, as snow on snow, as the bird in the air, and the planet on space in its flight, so do nations of men and their institutions rest on thoughts."

And again he says:

"The world stands on ideas and not on iron or cotton; and the iron of iron, the fire of fire, the ether and source of all the elements is moral force."

True it is that the nations and all their institutions rest on thoughts, and true it is that the world stands on ideas, and that moral force is the basis of all, the foundation of all; and as true is it that the thoughts which we instill into the minds of the youth in process of educating them, and the moral direction which we give, and the moral power which we cultivate during that work of preparation for the work of life, are the basis of all good that comes to the youth, and to the world through him, in later days.

It is said that there are two distinct educations—the old, or gymnastic, which develops the man and teaches him the use of his faculties, and the new, or technical, which teaches him to make use of the powers of mind and body that were given him by nature, and which are improved

by art, to make himself useful to himself and to the world. This is true, and yet it is not strictly true. Both are, or should be, parts of one education of which some may get the one part and some the other; but no man is educated until he has profited by both parts of the one unit. It is said that there is a conflict of studies, and it is oftener said that there is a conflict between great physical and great spiritual truths. The one statement is as incorrect as the other. As God's truths never conflict, so the principles of real education cannot contend one against another. There is no conflict between science and religion, though there may be between the scientific dogmatist and the dogmatic theologian; there is no conflict between the old and the new education, although there often come contests between the self-styled disciples of the one and of the other. We look abroad, over the wide and ever broadening field of human knowledge, and, as educators, it is our duty to cull from this infinity of knowledge, verging into the unknown, but to be known, beyond, so much of fact, truth, law, and of the systems of science, literature and the arts as will best suit our purposes for the time being, and best accomplish the results at which we aim. As knowledge increases, and more and more becomes accessible and useful and desirable, we are compelled occasionally to make a new adjustment of time and labor to the new conditions, and to revise our work and our scheme; but wise men are constantly making this revision, and the education of the moment is being continually ad justed to the needs and the opportunities of the time. In classical training we have found the form of education especially desirable for certain classes in the community, in scientific education that best for another, and in truly technical education that which is needed by still another class. But the really educated man will combine all of these; he will have a training that includes something of each of all the recognized branches of a liberal—in a broader sense than the classical—education, and will have soul and body, intelligence and muscle and nerve, all prepared by systematic cultivation for making the most of life. His intellectual gymnastic education has prepared him for the acquisition of technica knowledge, and for its application, for the rapid and effective acquirement of business experience and wisdom, as his physical gymnastics have made his body capable of exhibiting strength and endurance in the physical work of life. As the one follows the other, in natural sequence, the problem of education divides itself into two parts: 1st, the securing of the best preparatory education; 2d., the finding of the best system of technical and professional training.

In the evolution of the ideal system of education, therefore, we may anticipate many changes in the older systems and older methods, of which the often quoted words of Emerson undoubtedly to a certain extent are true.

Emerson has said: "We are students of words; we are shut up in schools and colleges and recitation-rooms for ten or fifteen years and come out at last with a bag of wind, a memory of words, and do not know a thing. We cannot use our hands, or our legs, or our arms. In a hundred high schools and colleges this warfare against common sense still goes on."

But the indictment is becoming less true each year. As Renan has said in his autobiography, the time is rapidly approaching when the student will give his principal attention to those branches of learning which definitely tend to give him at once disciplinary training and useful knowledge, which both strengthen and interest him. It is asserted that "the time will come when the older educations will no longer be predominant. The more we know of nature the more there will remain to be discovered. The natural sciences offer inexhaustible fields for research; and the truths which they reveal will prove more and more interesting to mankind." "Men of science are becoming more and more important factors in our lives. They are little by little winning the fight against disease; they are giving us facts, and enabling us to found our beliefs on the sure ground of knowledge. Their influence must undoubtedly increase as time goes on; and humanity always reserves its highest honors for those who teach it to do and to know."

It would be, perhaps, wiser to say that, looking out over our whole pantology, it is found that its boundaries are most rapidly extending in the direction of the

natural sciences and the sciences of application. To give the best education, therefore, it is necessary to constantly scan the ever-widening field, and to glean from its whole continually growing area the best for our present purposes. This must evidently include more and more of the newly-gained, the more modern portion, and the older education must be constantly in process of reconstruction to admit the new. There is thus no real conflict of studies; but the modified system compels more care on the part of the teachers of the older branches, and more skill in securing efficient work and in preserving the best, while pruning out the least needed part of the course. Wise men will adjust apparently conflicting interests, so far as they seem to exist, with the sole object of securing the best results of application of the available time of youth. Ordinarily, it should be the aim to first secure the best general education, and next the best possible professional education; but if, as is so usually the case, the student has not time for both, he must combine, with all the greater care, the disciplinary and the professional training in such time as he can give to the work. Thus securing the best education for himself, he is prepared to act his part well when those great social changes, called revolutions, take place, which are the mile stones of the progress of the race.

Technical education is the modern complement of the older, incomplete, academic education. It is simply the introduction into the scheme of instruction of that kind of professional training in industrial departments which has been so long familiar in the professional education of the physician, the jurist, the clergyman. It is the education which the great mass of the people need for the completion of their preparation for their life-work, after their preliminary instruction in the schools.

The ideal education would be such as should fit the citizen for successful pursuit of every desirable object in life, while enabling him to secure the capital needed for its complete attainment and thorough enjoyment. It would begin with the primary instruction demanded as preparatory to the studies of its later periods. The primary education would be followed by so much of secondary education, in the sense in which that term is now generally used, as should give to the youth the essential elements of a truly liberal education, such as should prepare him to continually advance into the unlimited fields of human knowledge; to gain from day to day, through all his after-life, more knowledge and higher learning in every division of science, literature and art; to enter upon the philosophical study of history, the comprehension of comparative philology, of the development of literatures; of the seductive and wonderful problems of mathematics; the no less wonderful principles and strangely beautiful phenomena of the physical sciences; the still more marvelous laws and operations of nature, as illustrated in the living creation; and, more than all, to some comprehension of the moral and the intellectual, sufficient, perhaps, to gain a glimpse of that great spiritual world of which the grandest minds and the loftiest imaginations which the human race has yet produced have never yet been able to grasp more than the most infinitesimal portion. A truly liberal education—and by this I mean vastly more than a strictly classical education, as we have seen—fits man to walk with his Creator in every field, spiritual, intellectual, physical, which the creature's faculties are given him to explore. From this point on, the education of the youth, now becoming mature in mind and body, must be made, usually, even where not before, special. He has been given the means and has been shown the way by which to enter into his wonderful heritage of the universe. Now, because he cannot grasp all, and because he must prepare himself for such complete knowledge of a vocation. and of all which is demanded for its successful prosecution, and because he may undertake a very small part of the work of the world, and that in a very restricted field, he must become a specialist, and must, in this work, confine his time, thought and labor to the acquirement of a profession, or a vocation. This must be the final period of his education; for, after entering upon his chosen life's work, he cannot usually expect to find opportunity to continue his education as an occupation. He must then buckle himself to the task, and take only such rare and short intervals for intellectual pursuits

as may be given him in his hours of rest and of rare leisure. This education, the ideal education, naturally divides itself into three distinct periods, devoted to three equally distinct objects. First comes the primary education, in which the child is prepared to begin the secondary portion of his work, which latter is the real beginning of a true education, of real intellectual acquirement and work; while the third period is that of professional education and training, a preparation for the vocations of life. And such should be the education of every human being, man, woman, or child in this nation.

But we cannot yet hope to see more than a very small proportion of the race, even in the most enlightened countries, pass beyond the first of these stages; and the greater number must for many a century yet, we may well fear, forego even the first. In our own country, fortunately, it rarely happens that a citizen may not, if prudent and industrious, find a way to secure for his children a primary education. A smaller number are able to obtain for their boys and girls special training in trades, or in the professions; and the number who can give their children a truly liberal education is lamentably small. The citizen who is so fortunate as to be able to supplement the primary education of the child by a technical training, foregoing the liberal education which he, probably more than his more fortunate neighbor, would desire to secure for the boy, may to-day well consider himself fortunate. But the numbers of such citizens are increasing year by year, and the technical school, usually distinct from the college, is becoming a recognized factor in our system of education. But the necessities of men compel a breaking up of the ideal system of education, and a setting off of the primary education, the liberal and the technical, each by itself, and each citizen gets what he can or what he chooses. Time may be expected to bring about changes in the direction of advancement, and to lead in the course of generations to the general adoption and acquirement of the ideal education. The ancients endeavored to train the individual; our own tendency is now rather to the acquirement of knowledge; while the real education, the gymnastic combined with the technical, the liberal with the professional, will confer upon the man all the great divisions of human knowledge. This union of all forms of education is not new as a scheme of instruction, though so novel in practice. The Greek aimed to unite all mental with all physical training. Plato would have children trained by the state in order that they should be prepared to do all that the state demands of the citizen. He would teach science as well as philosophy. In the Middle Ages the education of the youth was literary in the cloisters, but it was practical and professional in the castle; and some of the young knights of those strange days were so fortunate as to have the benefit of both kinds of instruction, pursuing the "gentle arts" as well as practicing those of war. Even the monks of the dark ages, however, taught arithmetic, geometry, and astronomy; and every knight in the days of chivalry was desirous of so much knowledge of language and literature, at least, as would enable him to read the tales of errantry, and to make verses complimentary of the beauty of his lady. Among the great universities which arose in the twelfth to the fifteenth centuries, many taught the learning of the professions; and some became mainly professional schools, as Bologna in law, and Salerno in medicine. Luther "led the schoolmaster into the cottage," and laid the foundation of the existing German system of education of the whole people; and Melancthon did his part toward the revival of literary instruction. The reformation of the church and the schools went on side by side. Sturm, Ratke and Comenius, were the leaders in a revolution no less complete and no less important than were those inaugurated by the great ecclesiastics of the preceding generation. John Locke inveighed against current useless knowledge, and insisted upon the inculcation of those forms of mental action which best fit the man for the duties of life; while Milton, pointing out "the right path of a virtuous and noble education," seconded the demand of Comenius, that the "learning of things and of words" should be carried on together. He considered agriculture, architecture, engineering and navigation no less important than the languages, literature and mathematics. He would make

of his men warriors, citizens and athletes, as well as scholars. Matthew Arnold ascribes the wonderful achievements of Prussia during the past generation to the fact that, in the system of education so wonderfully there developed, every man is taught his business on the best plan that can be devised; and it is this which that great author desires to bring about, as well as the education of youth in the humanities. Arnold's cry for better instruction in science and the professions, and the earnest, almost pathetic, appeal of John Scott Russell twenty years earlier, for systematic industrial and professional training, are, but the echoes of the voices of many wise men of earlier times. The Marquis of Worcester, two centuries ago, sent out the same warning from the depths of his dungeon, where he had been forced away from his wonderful invention, the "fire engine," the steam-engine as it had been later named, that was echoed again from across the channel by the great mechanic Vaucansen. But the actual institution of a system of technical education was left to the German and French nations within the last century, and upon the great scheme of general and practical, as well as liberal, education by them organized, the strength and wealth, and the intellectual progress of those great nations are based. And thus the seeds sown fifteen and a half centuries ago by St. Basil, of Cæsarea, in whose workships the "poor wayfarers" might learn the essential principles and the methods of practice in the various "pursuits and professions of life," have finally borne fruit in the enriching of nations. A century ago Count Rumford established technical schools for the beggars of Munich; to-day the whole of the German and the French empires are established, socially and financially, very largely upon just such schools; and the English-speaking nations are just beginning to profit by the precepts of that illustrious tory. The ideal education proposed by the great Descartes is just coming into actual realization, here, among our people, whose habits, customs and traditions are such as may be expected to permit its fullest and most faithful development.

In this development of the modern educational structure, the process has been very like that described by Dr. Whewell, who, in his history of the inductive sciences, says, "The earlier truths are not expelled, but absorbed, not contradicted, but extended; and the history of each science which may appear like a succession of revolutions, is in reality but a series of developments." * * * "Thus the final form of each science contains the substance of each of its preceding modifications, and all that was, at any antecedent period, discovered and established, ministers to the ultimate development of its proper branch of knowledge."

Thus, in education, the development of the latest phase of a continually growing system illustrates the evolution of a more perfect and complete from a less developed and less complete form; and the process of construction has been one of accretion, part by part, the whole assuming a more perfect form as the process continues, until now, as we approach the period of completed growth and enter upon the perhaps final stage of progress, we can at least begin to appreciate the fact that we have here also an illustration of the operation described by the great writer from whom I have just quoted. Some years ago, in tracing the history of the development of the modern steam-engine, I was greatly interested in observing how strictly its growth illustrated this same method. So strongly did this strike me that, in planning the written history, I divided it into the several periods of speculation, of application in several distinct forms, and, finally, a period of refinement. So, it would seem, we are now brought, in the history of education, to a "period of refinement," in which all the elements of the complete system being present, the efforts of nations are directed towar their selection, arrangement, and mutual adjustment, to form a complete and symmetrical whole of maximum efficiency and as perfectly as possible adapted to the purposes which the experience and the wisdom of a world has found essential. In studying this development and this final unplanned but no less systematic reconstruction of the whole, it is interesting to observe how generally the several reformations, and the various attempts to secure an ideal beyond and outside of existing methods and schemes, have been inaugurated by individuals,

and how seldom by governments. The Conservatoire des Arts et Metiers, at Paris, was founded upon the basis of the collections of that inventor and wonderful mechanic, Vaucanson. L' Ecole Centrale was established by Dumas, Pictet, Ollivier and Lavallée, the latter supplying the funds, and the three professors the no less needful, and even more rare, contributions of knowledge, genius and organizing talent. In these latter days we observe the same characteristics of this development of the perfected form of education, and nowhere more prominently than in the United States. The organization of the institutes of technology and the various technical and trade schools in this country—and of the academic schools as well, I should add—has largely been the work of private philanthropy and patriotism. We rarely see a reference to their growth that is not accompanied by an acknowledgment of our indebtedness, as a nation, to men like Chauncey Rose, like Ezra Cornell, Hiram Sibley, Edwin A. Stevens and Asa Packer, like Sheffield and Lawrence, and Case and Van Renselaer, and many others scarcely less distinguished as benefactors of the country and of their race. It is a comfort to find so many of our craft enrolled on this splendid list, who have splendidly supplemented that grand gift of the nation to the people, on which are founded the "land-grant colleges."

Another thought comes to the student of this recent phase of our social life and growth. The period of refinement upon which we have now entered is one of adaptation of the work of instruction and its methods to specific purposes, of application to definite lines of work, having as definite and as special objects in view. The process of refinement is thus, in this sense, a process of specialization, just as, in every industrial department, the later developments have all been in the same direction of exact production and reproduction of exceedingly nicely-defined, exactly shaped and precisely measured objects for the use of man. It is thus that we have come to the period of expansion of special schools and special departments of technical application of the laws and principles of the mathematics and of the natural sciences. Just as in a watch factory, we have one machine to turn out a pinion, another to make its arbor, one to produce a pallet and another to make the plate; so in our education of youth, we now have one school to give special instruction in civil, and another in mechanical engineering; one to give the aspirant for distinction in natural science his training, and another to make him a physician, a lawyer, or a minister of the Gospel. For these are all technical schools. Each has for its office the preparation of the young man who is about to go out into the world to conquer what it may have in store for him, in such a manner that he may best, most promptly, most economically and most efficiently, acquire the practical knowledge, and most readily and fully profit by the experience which is thus offered him. The term "technical" will not bear restriction to our schools of engineering or of applied science, in the sense in which that restriction is commonly attempted. The older schools of law, of medicine, and of divinity, and their young relatives, those of engineering and the trades, all belong to one category, and come under the common designation, properly, of technical schools. The technical school is thus seen to be the result of that specialization which is everywhere making all processes, all departments, all forms of industry, whether manual or intellectual, more efficient and more productive. Every phase of modern civilization and of modern life illustrates this refinement of all arts, and of all social processes by specialization; and the technical school is merely one of its latest examples.

I have sometimes asserted that the work of technical instruction in the arts must, for effective action and maximum efficiency, be still further specialized, and that the solution of that educational problem which now most interests us must be found in the subdivision of the work of the technical schools relating to the constructive arts, which should be distinguished by a natural system into three principal kinds—the manual training school, the trade school, the school of engineering. The first should be planned with a view simply to the instruction of boys—and girls—in the use of the various tools used in the constructive arts: the second should teach the trades, and their theory and fundamental principles of practice, as well as the ap-

plication of the skill acquired in the first kind of school, while the last and highest grade should be so organized and conducted that the student, now mature and well grounded in the fundamental studies, shall be able to secure a good knowledge of the principles of applied mathematics and of applied science, as illustrated in the practice of the designing and of the constructing engineer, and a knowledge also of the methods of practical work, so far as they may be taught and illustrated in the school; while he is also given a good idea of the relations of the several trades to the professional work of the engineer. In the manual training school the boy learns to use his hands and handle tools; in the trade school he learns the method of some trade; in the school of engineering he learns the principles of design and the ways in which the trades may be made useful to secure a result set forth as to be attained. It is not at all the fact, as at least one of my friends among the critics has asserted, that this is a system of caste distinction; it is merely a system of careful adjustment of means to ends, and of furnishing the learner just the knowledge that he at the instant desires, in the most accessible and available possible form. It is the construction of an educational machine to turn out the kind of product that is wanted, and the citizen has perfect freedom of choice as to which kind of apparatus he may avail himself of. The boy who is best fitted to learn one trade, and to excel in that, is very likely not the boy who is best adapted to profit by the opportunities especially offered by the school of engineering. The young man who is to become a designer of costly and complicated machinery, and who should therefore go through the last mentioned school, might prove a failure as a workman at the trade in which the former may become distinguished above all his fellows. Each possesses, often, a distinct sort of talent, and is best fitted for his special line of professional work.

Thus, by a slow and fitful perhaps, but never-ceasing progress, we are evolving the best system of education of the youth of our country and nation. Technical education is the apparently last phase in this evolution; but the evolution of the various general and varieties of technical education is likely to continue to be the essential feature of further social progress for many years, and probably for generations still to come. This process of development of the best means of preparing the individual and the race for its work in the world will undoubtedly continue to improve in its efficiency and in adaptation to the needs of the people until, and we may hope in a not distant future, every citizen shall have the opportunity to prepare, through a very perfectly devised system of education and training, for his work, and for his mission of good in the world. Technical training will reach, each year and each generation, further down toward the lowest strata of society, until, finally, every man, every woman, and every child shall have the privilege of receiving a real education, such as is best suited to the best interests of the individual. Every vocation, every position in life, will be taken into this beneficent scheme of advancement of humanity.

What we see around us, on every hand, great as is the work, splendid as is the fruitage of this modern tree of knowledge, a fruitage wholly good, is but the seed of a mighty harvest, yet to come, such as it is probably impossible for the most sanguine among us fully to realize, either in relation to its immediate, or its more important remoter, results.

I have said that we are to hope for a development of real and complete, a true and a vivifying education that shall in time enable the world to avoid the terrible consequences of those great political and social convulsions which have from prehistoric times been the milestones of human progress toward better things. Every human being may be expected to be affected, if not absolutely controlled, by four sets of conditions, and their resulting influences. Politically, the citizen is more or less under the control and in the power of the government under which he happens to live, and is subject to laws which bear, with a force he cannot control or evade, upon every condition affecting his life, his liberty and his endeavors after happiness. Socially, he is tied into an industrial system in which he may have a certain amount of freedom of movement and of choice of vocation, but he is nevertheless as firmly bound as a part of the system as, politically, he is secured under a code of law. He must

do his part, both as a citizen, as one unit in the national whole, and as a worker, one unit in the great industrial body. Another tie of the average citizen is that of the family, and he is controlled and commanded by this bond no less firmly than by the others. Finally, every individual is more or less governed by those personal interests which mainly affect him alone, and make up his life as an individual, those which relate to his personal life, apart from the lives of those about him, and which are not absolutely controlled by his relations to others, such as good and bad habits, the traits of the individual character.

A perfect system of education will prepare the individual to make the most of life for himself, to enjoy its pleasures, to gain its rewards and to absorb all that life can offer him as an independent existence. It will prepare him to care effectively for his family and to readily gain for them all that is necessary for their comfort and happiness in this life. It will prepare him to take his place in the industrial system, and to do his work in the world so efficiently and with such satisfaction to himself and others that he may contribute the most possible to the stock of good things possessed by the world and the race. It will, finally, prepare him to take his place in the political structure, and to do his duty as a citizen in such a manner that the government to which he owes allegiance shall be made more efficient by the fact of his existence.

And thus the nation's great problem will be finally solved. Humanity, trained and educated, conscious of and obeying, whilst making the highest use of, all moral forces and of all moral law, intellectually developed to a maximum of strength, wisdom and foresight, physically prepared to force every natural agent to its own purposes, possessing in its mighty self-acquired powers, genii more numerous and more powerful than ever Aladdin knew, compelled in its course toward the destiny leading it away on into eternity, may yet be able to evade all such vexations and trials as have, in the eternity of the past, fretted its course, and may make progress as smooth as it is inevitable. The revolutions, the periods of darkness, the now often-recurring times of distress, will be found to have causes which are ascertainable and removable, political causes dependent upon conditions that a wise statecraft may comprehend, and assisted by intelligence, wisdom and patriotism on the part of the people, may remove; industrial conditions which a better knowledge of and a wiser dealing with the laws of labor and of supply and demand will adjust so that progress shall be made steady and smooth and easy, and fruitful of good to all; social causes, which the education and training of the people and the preparation for the duties of life may, in the main, dispose of, leaving every honest and well-meaning citizen safe against periodical distress, capable of securing for himself and for those dependent upon him all that is needed to make life comfortable and enjoyable, and to enable him to do his part in relieving the weak and unfortunate, whose number, generation by generation, will become a smaller and smaller proportion of humanity. Thus it is, we may hope and firmly believe, that the great perturbations of the mighty current of human progress may gradually become less and less frequent and less violent, and the ideal education bring to the whole world more and more completely all the possibilities that mortals do most desire. Nations, no longer exposed to destructive blasts from the cloudy regions of ignorance and passion, will not flourish only to decay but will grow indefinitely, stronger, wiser, better, each helping the other toward a better future; progression will be continuous; governments will govern for the people; the industries will yield all that the world needs and demands, without crushing the workers, and all men will come to an intelligent use of lives into which will be incorporated so much of leisure as is needed for the soul's best interests, and the intellect's highest aspirations. We may even anticipate that the wealth of the world will be, by wealthy men, more and more directed into channels in which it shall most and best advance the noblest desires of the race. We may be sure that the great men who have been the pioneers in the work of introducing what is needed to complete the structure and to aid the evolution of the ideal education, and whose monuments we see around us, will have a following which, as time passes, will become continually more and more numerous, through all coming cen-

turies, until a great army of these fortunate citizens shall find most glorious work in making life better and brighter for their fellows; it will be to them, more than to all others, that the race will offer the greatest honors through all the coming years, as to those who have done most to make bright its course and its destiny, and to solve the great problem of the nations.

RECENT ADVANCES IN SANITARY SCIENCE.

From "Nature."

"Hygiene," in the words of the late Professor Parkes, "is the art of preserving health; that is, of obtaining the most perfect action of body and mind during as long a period as is consistent with the laws of life. In other words, it aims at rendering growth more perfect, decay less rapid, life more vigorous, death more remote." The art of preserving health is correlative with the science of prevention of disease, since perfect health means the absence of disease and of tendencies to disease. Hygiene is thus the art of preserving health and the science of preventing disease; and in taking into account recent advances in sanitary science we must consider recent acquisitions in our knowledge of the origin, causes, and spread of disease, more especially of those diseases known as "preventable," as well as the methods of improving the natural conditions or social relations surrounding us, which are instrumental in preserving health and counteracting disease.

The etiological relations of all diseases are a subject of interest to the sanitarian, but those which have received the most attention of recent years, and in which the most striking advances of knowledge have either already been made, or are imminent in the near future, are perhaps Asiatic cholera, typhoid or enteric fever, diphtheria, and phthisis or tubercular disease of the lungs. The mode of origin and spread of Asiatic cholera has attracted great popular attention, both on account of its possible introduction into this country from infected districts of the Continent, and from the alleged discovery by Koch of a *spirillum* or *comma-Bacil-*

sserted to be the specific cause of this terrible disease. The Report of the Government Commission, consisting of Drs. Klein and Heneage Gibbes, who visited India in 1884 with the object of undertaking researches into the etiology of Asiatic cholera, has lately appeared, and in this Report the conclusions arrived at by Koch from his own researches are very directly traversed. This Report, too, has received a very cordial support from a committee consisting of many eminent physicians and physiologists, which was convened by the Secretary of State for India for the purpose of taking it into consideration. It must be apparent, however, to any one who makes an impartial study of the literature of the subject, that, if Koch's organism has not yet been proved to be the actual cause of the disease, it has been proved to differ from all other organisms asserted to be identical with it, from the fact that its growth in various nutrient media is characteristic, and serves to distinguish it from all other organisms. As far as our knowledge at present extends, difference in manner of growth in nutrient media affords as just a basis for distinction between micro-organisms as difference in microscopical appearance or other morphological characteristics. Koch's comma-Bacillus is therefore diagnostic of the disease, and this fact has now placed in the hands of medical men the power of at once recognizing a true case of Asiatic cholera, the isolation of the organism from others in the choleraic discharges and its cultivation in suitable media being alone needed. The results of Koch's researches, whether fully accepted or not, have not affected, nor are they likely to affect, the measures on which reliance alone can be placed for the prevention of outbreaks and spread of the disease. In the words of the committee before alluded to, "Sanitary measures in their true sense, and sanitary measures alone, are the only trustworthy means to prevent

outbreaks of the disease, and to restrain its spread and mitigate its severity when it is prevalent. Experience in Europe and in the East has shown that sanitary cordons and quarantine restrictions (under whatsoever form) are not only useless as means for arresting the progress of cholera, but positively injurious."

The view that typhoid fever cannot arise *de novo*, but is always propagated by a specific contagion from a previous case of the disease, is steadily gaining ground, as the number of epidemics where the disease has been definitely traced to specifically polluted air or water increases. In many other cases, although the specific pollution has not been definitely proved, the probabilities in favor of such a view have been very great. No micro-organism has yet been found which can lay claim to be regarded as the specific contagion of the disease, but we are in possession of so many facts concerning the mode of origin and spread of this disease, that any discovery of that nature would probably not greatly affect the measures now taken for its prevention.

The etiology of diphtheria has lately received very careful study, but so far without the attainment of any results capable of exact formulation. It is not a disease invariably dependent on insanitary conditions, such as typhoid fever is, but that such conditions favor its spread and severity is more than probable. The far greater comparative frequency of diphtheria in rural districts than in large towns in this country is well known, and has been attributed to the presence in the air of the latter of the products of coal combustion. This view appears the more probable seeing that Continental cities, where wood and not coal is chiefly used as fuel, enjoy no such comparative immunity from the disease. Excessive moisture in the air of a house, whether arising from defective construction of the walls or roof, or from a water-logged soil, are conditions very often associated with diphtheria. The fact also that the disease is most prevalent in the damper seasons of the year, when vegetable matter is undergoing decay and fungus life is most active, favors the theory that the specific contagium of this disease is a mould or fungus, which flourishes most strongly in a damp and smokeless air. It is a remarkable fact that diphtheria is sometimes associated with scarlet fever in one epidemic, the two diseases appearing to be interchangeable; but this is a subject that requires further elucidation. The contagion of diphtheria is extremely persistent and long-lived, clinging with great pertinacity to infected articles, so that every article which is likely to have become contaminated requires very thorough disinfection, preferably by heat. There can be no doubt that school attendance is often a chief factor in the propagation of the disease amongst children.

Koch's discovery of the *Bacillus tuberculosis*, a micro-organism now proved to be the specific contagium of tubercular disease in men and animals, has placed tubercular phthisis in the category of contagious diseases. A peculiar disposition or tendency, whether hereditary or acquired, is no doubt wanted to enable the germ to take up its habitat in the human lung, but the fact that this idiosyncrasy can seldom be definitely recognized renders great caution necessary both on the part of members of a family in their association with a consumptive relation, and of hospital authorities in admitting into a general ward cases of tubercular disease, or of massing together into one institution patients in every stage of the disease. The Bacillus is constantly present in the sputum and probably in the breath of phthisical patients, and this points to the necessity of free ventilation of living and sleeping apartments, and disinfection of soiled articles of clothing and furniture. The external conditions which, of all others, cause a predisposition to consumption are, a damp subsoil, causing excess of moisture in the air, and the constant breathing of an atmosphere vitiated by human respiration. It has been asserted that tubercle can be propagated from animals to man by the consumption of diseased meat, or, in the case of the cow, from the milk of a tuberculous animal. Further proof is required before we can accept such an hypothesis, but there is nothing improbable in such a mode of conveyance of the disease, especially in the case of children with a tubercular predisposition.

Besides the diseases which we now know to have been propagated through the agency of milk—enteric fever, scarlet fever, diphtheria, etc., in which the in-

troduction of the morbid matter is accidental, the milk serving only as a means for its conveyance and perhaps for its growth—there is a complaint fairly definite in character, which has been attributed to the consumption of the milk of cows suffering from foot and-mouth disease. Here the morbid quality is inherent to the milk as taken from the cow, and is not due to an accidental introduction. The symptoms described in the epidemics recorded are fever, vesicular eruptions on the lips and in the throat and mouth, and enlargement of the glands of the neck. During the prevalence of foot-and-mouth disease, all milk taken by a household should be boiled before consumption. In view of the many dangers which threaten us through the agency of milk, it would perhaps be advisable, especially where children are the chief consumers, that this precaution should be always adopted; at least until the sanitary authorities in towns have the power of inspecting and controlling the farms and dairies in the country from which the chief part of the milk-supply is derived.

The possibility of the transmission of the contagion of small-pox for considerable distances, not exceeding one mile, through the air, has been warmly supported. There are many facts in favor of such a view, and its great probability will be seen from the following considerations. The contagion is almost undoubtedly a micro-organism of the class Bacteria, but as it has not yet been isolated and identified, we are unaware if it is capable of spore-formation or not. The spores of Bacteria can resist external agencies—heat, cold, drying, and antiseptics—to a much greater extent than the fully formed organisms, and it is probable that those diseases in which the contagion remains dormant for long periods are transmitted through spores capable of existing for long periods outside the body. But in small-pox it is not necessary to rely upon spore-formation to support theories of aerial transmission. The contagion as given off from the body of the patient is inclosed in minute epithelial scales and dry pus accumulations. Here, protected from the air and from external destructive agencies, it may be wafted as a minute dust through the air, to descend at considerable distances. That the radius of infection from a small-pox hospital as a center does not exceed a mile may be due to the great dilution of the contagion as it is diffused through greater distances than a mile from its center of origin, the hospital. The observations of Dr. Miquel, at the observatory of Montsouris, near Paris, have shown the number and variety of solid particles which are carried in the air, and the immense distances which some of them, as pollen and spores, may be presumed to have traveled. An educated public opinion will soon, if it does not already, regard small-pox hospitals as possible centers of infection, and will insist on their removal outside inhabited areas.

The compulsory notification of infectious diseases to sanitary authorities, either by the householder in whose house the case occurs, or by the medical attendant, or by both, has been adopted in numerous provincial towns during the last five years. This measure has done much to furnish the authorities with early information of the occurrence of infectious disease which would not otherwise have been obtained, and such information has doubtless enabled the sanitary officials to stamp out many an epidemic in the bud, which might otherwise have reached large dimensions. The more universal adoption of a measure of compulsory notification in our large towns is urgently needed.

In the domain of domestic sanitation the advances of recent years have been mostly limited to the practical applications of sound principles already acquired to the carrying out of works of construction, drainage, or water-supply of the dwelling. Houses built for the use of the well-to-do classes (not those of the speculative builder) in recent years will most generally be found to be planned and fitted on modern sanitary principles. Thorough ventilation of the drain and soil pipe, disconnection of the waste-pipes of baths, sinks, and lavatories, and of the overflow-pipes of cisterns from the drainage system, are now understood to be necessaries of modern life. A break in the connection between the house drain and the public sewer by means of a manhole chamber and water-seal or trap, though not considered necessary or desirable by all, is

now very usually practiced. We cannot doubt that the air of a public sewer is sometimes the means of disseminating disease, and any method which practically excludes such a source of danger from our houses is one to be encouraged. As knowledge extends, the simplest form of apparatus is found to be the best; many of the more complicated kinds of traps and contrivances for excluding sewer air are now discarded by builders and architects for those simpler forms which are equally effective.

In the matter of water-supply, the belief is steadily gaining ground that a water once polluted by sewage cannot be regarded as safe for drinking purposes. Safe it may be so long as filtration on the large scale is efficiently performed, but any failure to thoroughly filtrate and aerate the water in times of epidemic visitation might be attended with disastrous consequences, even supposing that filtration through sand and gravel is destructive of disease organisms or their spores. The introduction of a constant supply of water into towns, in the sense that cisterns and receptacles for storing water are no longer necessary, has been of great benefit—especially in the poorer parts of towns, where water stored on the premises is usually highly contaminated.

Of the scientific witnesses who were examined before the Royal Commission on Metropolitan Sewage Discharge, nearly all were in favor of the principle of separation of the rainfall from the sewage. "The rain to the river, the sewage to the soil." In view of the ultimate disposal of the sewage, the advantages of the "separate method" are very great, and would now probably lead to its adoption in any new scheme of sewerage for a town where the circumstances are favorable. From the public health point of view, it is also desirable to have impermeable pipe or brick sewers of small size, so that contamination of the soil by leakage into it of the contents of sewers may be avoided. In any such scheme of sewerage it must not be forgotten that not only are channels on the surfaces of the streets and roads required to convey away surface water, but pervious drains laid in the subsoil are absolutely necessary in the health interests of the town to keep the subsoil water at a permanently low level. For the disposal of the sewage, the value of a regular daily flow, and the elimination of the necessity in times of heavy rain, of dealing with an enormous and uncontrollable volume of dilute sewage, must be obvious. The surface waters of towns are certainly not clean, but where the streets are efficiently scavenged they are free from taint of human excretal refuse, and fit for admission into the rivers which nature intended as drainage channels of the surrounding high lands.

The extreme importance of thoroughly ventilating sewers, is now very generally understood. Pipe sewers require as much ventilation as brick sewers, although the absence of deposit on the smooth internal surfaces of the pipes, and their consequent freedom from smell due to decomposition of deposited organic detritus, originally led to the belief that ventilating openings were not required in pipe systems of sewerage. It was not until Dr. Buchanan showed in the case of Croydon that the absence of proper ventilation in the pipe sewers of that town was in all probability instrumental in aiding the spread of enteric fever, that the opinion of engineers on this matter underwent a change. Displacement of air in pipe sewers of small diameter is greatly more sudden than in brick sewers of larger diameter, and it is plain, says Dr. Buchanan, that "means of such ventilation are wanted more numerously in proportion as the displacements of air may be local and sudden." Openings into sewers from the street level are still regarded as the best practicable means for the admission of fresh air, and the exit of sewer air. Charcoal trays, Archimedean screws, and other contrivances for purifying the issuing air, or hastening its exit, are now generally abandoned as useless and inconvenient.

The purification and utilization of the sewage of towns is a subject of much importance both in its public health and commercial aspects. The idea, so long entertained, that town sewage could by various methods be made to yield a manure which would give rise by its sale to an enormous profit, is now exploded. The highest degree of purification, we now know, can only be attained on land naturally suitable from its porosity and other properties, and artificially prepared

by extensive under-drainage. The agents which purify sewage in its passage through soil, by converting the nitrogenized organic matters into inorganic salts—nitrates and nitrites of the alkaline and earthy bases, and ammonia—have been discovered to be bacterial microorganisms, resident chiefly in the superficial 18 inches of soil, and far more abundant in some soils than in others. Sewage farming has been ascertained to be profitable, under suitable conditions. The sewage must flow from the town to the farm by gravitation—the cost of pumping will neutralize profits from the sale of farm produce: a part of the farm must be laid out as a filter bed, so that the sewage, when not required on the cultivated land, or when so dilute from the presence of storm waters as to be inapplicable, may be purified on a small, very porous area, by the process of intermittent downward filtration. Very few growing crops are benefited by the application of sewage, except the various kinds of grasses, and of these such enormous quantities can be produced that, unless converted into "silage," or utilized on the farm in the production of stock and dairy produce, they may be expected to result in a loss, from the absence of any demand for such large quantities at all periods of the year.

In this country, the sewage farm at Birmingham is probably the best example of what has has been done to solve a most difficult problem by the application of sewage to land. Here, the sewage is first freed from its suspended matters by a process of precipitation, a proceeding necessary not only to prevent warping of the land with offensive solid matters, but also to withdraw the metallic salts and acids incidental to the sewage of a manufacturing town, which would be injurious to vegetation. Even this magnificent example of dealing satisfactorily with the most difficult municipal problem of modern times is eclipsed by the city of Berlin on the Continent. The sewage farms at Berlin have successfully dealt with the sewage of 887,500 people—nearly twice the population of Birmingham—whilst London is still allowing to run to waste an enormous amount of valuable material, at the same time polluting a river—the highway of its commerce—to an extent never previously dreamt of.

Processes of precipitating sewage by chemicals are now known to exert only a partially purifying influence. The best process yet discovered can do little more than free the sewage from its suspended matters, allowing all the dissolved constituents of sewage—by far the most valuable portion, agriculturally and chemically—to pass away in the effluent. Lime dissolved as lime water, sulphate of alumina, and perhaps proto-sulphate of iron, taken together and added to the sewage in the proportion of not more than 10 to 15 grains to the gallon, are the best, most economical, and most effective precipitants. Other more valuable substances, added to the sewage with the view of increasing the value of the precipitated sludge or manure, are in large proportion lost in the effluent water, and as they do not assist precipitation, might just as well be added to the sludge afterwards, if fortification is required. Half-a-crown and no more is the value per ton of the precipitated solids of sewage. This value will generally pay for the cost of their carriage a mile or so in agricultural districts, but no further.

A great improvement in dealing with the semi-liquid sewage sludge has been lately effected. The sludge containing over 90 per cent. of water was formerly allowed to dry in the air or in a drying chamber, and a most intolerable nuisance resulted. It is now possible by means of hydraulic filter-presses to convert the semi-liquid sludge into solid cakes containing 40 to 50 per cent. of water, and in this form it is innocuous to the senses, and can be readily conveyed away by cartage.

The knowledge already acquired demands that now, and in the future, the sewage of towns should, whenever possible, be utilized on land in the production of crops or dairy produce; failing this, the sewage should be freed from its solids by precipitation, and subsequently purified on land laid out as filter-beds, efficient purification, and not the production of crops, being alone aimed at. If application to land is impossible, then precipitating processes alone must be relied on, and where the sewage can be turned into the sea, and effectually got rid of without nuisance, there it may be allowable to waste valuable matter which cannot be utilized except at a cost destructive of all profits from its utilization.

INVESTIGATION INTO THE STRENGTH OF STEEL AND WROUGHT-IRON GIRDERS.*

Abstracted by WILLIAM ANDERSON, M. Inst. C.E., from a translation by H. SICCAMA, M. Inst. C.E.

From Selected Papers of the Institution of Civil Engineers.

THE girders experimented on were all beams with single-plate webs having flanges composed of angle-bars, and two or more layers of plate.

The paper commences with some explanatory and introductory matter, and proceeds as follows:

On the 23d of February, 1877, in the works of the firm of Harkort, at Duisburg, Hochfeld, a riveted longitudinal beam was placed on two supports, and weighted on the center until rupture took place. The beam rested near its extremities on wrought-iron rollers. The pressure on the center of the top flange was applied by a lever 31 ft. 2 in. long, with a ratio between the arms of 1 to 29. By means of a screw at the fulcrum, the lever could be kept in a horizontal position during the deflection of the girder. Lateral deflection was prevented by four angle irons which supported the horizontal flanges sideways.

The scale-pan at the extremity of the lever was slowly and carefully loaded; the girder stood the test well until the calculated tension in the extreme lamina had reached 12.7 tons per square inch (20 kilograms per square millimeter). Up to that load the observed deflections were less than those calculated, but with the above strain they became equal to it. When the stress had reached the supposed limit of elasticity with a calculated tension of 15.9 tons per square inch (25 kilograms per square millimeter) a peculiar snap was heard, followed by a similar report a second later, after which the girder broke through the middle with a loud noise. The fracture showed a clean, bright metallic surface, without any blemish which could explain the unexpected failure.

On the 19th and 20th of March two longitudinal girders of the same form were tested in a similar way. To distribute the pressure more evenly, a cushion measuring 6.56 ft. by 1 ft. $2\frac{1}{2}$ in. (2 meters by 370 millimeters), made of felt, oak, and iron plates, was placed under the test load on the girder. A snap was heard when the first of these girders was loaded to a calculated tension of 15.2 tons per square inch (24 kilograms per square millimeter). The lower flange of one of the bottom table angle-bars was fractured. No exceptional brittleness or hardness could be inferred from the appearance of the fracture.

The strength of the third girder proved to be even less. A calculated tension of 6.3 tons per square inch (10 kilograms per square millimeter), was successfully supported, but two reports were heard at a tension of 7.6 tons per square inch (12 kilograms per square millimeter). The deflection then was but small; the fracture could not easily be found, and the experiment was proceeded with. When the tension reached 11.7 tons per square inch (18.5 kilograms per square millimeter), another report was heard, and at 12.7 tons per square inch (20 kilograms per square millimeter), a rent was discovered in one of the lower angle bars. A tension of 14.1 tons per square inch (22.2 kilograms per square millimeter), caused the lower flange plate to tear with a report. At 17.8 tons per square inch (28 kilograms per square millimeter), the two lower angle-bars broke, and the bottom flange was ruptured in a second place at 2.62 ft. (800 millimeters) distance from the first fracture. With 21.5 tons per square inch (33.9 kilograms per square millimeter) tension, the lower flange plate and angle bars were fractured for the third time. The girder, with its lower flange broken in several places, bore the slowly-augmenting load until a strain of 24 tons per square inch (37.8 kilograms per square millimeter) had been reached when total fracture occurred. Immediately after this, parts of the broken

* The original appeared in the Tijdschrift van het Koninklijk Instituut van Ingenieurs, 12 Feb., 1884, and contains ten plates, besides numerous tables. The MS. of Mr. Siccama's complete translation, with all the plates, diagrams, and tables, are in the library of the Institution.

girder near the fracture were drilled out and submitted to tests in compression and tension. These last gave satisfactory results on the whole, indicating an ultimate strength of 38 tons (60 kilograms) to 47.6 tons (75 kilograms per square millimeter) per square inch. The elongations amounted to a maximum of 21 per cent. and a minimum of 13.5 per cent., and the contraction of the sectional area varied between 26 and 41 per cent. Some of the rivet heads were cut off to ascertain whether the rivet holes had been properly filled. This proved to have been the case.

From the 11th to the 14th of April, 1877, three steel longitudinal beams were tested at the Union Works, near Dortmund.

The beams were supported at their extremities on steel rollers, resting on piers of masonry, and were loaded by dead-weights laid on a platform suspended from the beams by four rods. In order to place the weight on the platform slowly and without shaking, the rails, which served as weights, were first laid over an iron beam placed on each side, and arranged to be lifted or lowered by means of screws. The lifting or lowering never exceeded a rate of $\frac{3}{4}$ in. per minute. Four angle-irons were fixed in order to prevent the platform swaying sideways. Lateral deflections of the tested beam were also guarded against by angle-irons fixed vertically. The deflection in the center was observed on the bottom flange by direct measurements, and on the top flange by means of a special apparatus designed to magnify the readings.

The loading was regulated so as to cause calculated consecutive tensions in the extreme lamina of 6.3, 9.5, 11.4, 12.7, 15.2, 16.5 tons per square inch (10, 15, 18, 20, 24, 26 kilograms per square millimeter). After this tension had been reached, the stress was increased by 1.27 ton per square inch (2 kilograms per square millimeter) at a time, to 25.4 tons per square inch (40 kilograms per square millimeter), after which the gradual increase was at the rate of 0.63 ton per square inch (1 kilogram per square millimeter) at a time. Up to a tension of 17.8 tons per square inch (28 kilograms per square millimeter) the load was completely lifted off, after the deflection had been taken, by means of the screws. Above this limit the beam was totally unloaded at every 6.34 tons per square inch (10 kilograms per square millimeter) increase only in order to save time. All weights causing a tension of over 19 tons per square inch (30 kilograms per square millimeter) were left on for some minutes before adding to them. The three girders tested stood a tension of 21.6 tons per square inch (34 kilograms per square millimeter), and carried a load of 57.7 tons (58,588 kilograms) without any unfavorable symptoms being observed. The deflections agreed pretty well with the calculations. With a tension of 21.6 tons per square inch (34 kilograms per square millimeter) on the first girder, a snap was heard, and a rent discovered on the lower flange plate. With a tension of 24.1 tons per square inch (38 kilograms per square millimeter), the girder broke in two, the lower angle-bars being torn in two or three places.

The second girder tested stood a tension of 24.1 tons per square inch (38 kilograms per square millimeter). When the stress had increased to 25 tons per square inch (40 kilograms per square millimeter), the platform was found to be unevenly loaded. Before it could be lifted, previous to readjustment, a snap was heard, and a rent found in the lower angle-bars on the over-weighted side of the platform. Reports were heard twice after resuming the experiment, and a second fracture was found in the lower angle-bars; the girder broke in two when the calculated tension had reached 27.9 tons per square inch (44 kilograms per square millimeter).

In testing the third girder, the first report was heard just before the tension of 24.1 tons per square inch (38 kilograms per square millimeter) was reached. No fracture could be found, but the complete fracture followed with a tension of 26 tons per square inch (41 kilograms per square millimeter).

The surfaces of the fractures were those characteristic of good ductible steel. Strips were drilled from near the fractures, and tested for toughness and ductility. The strength amounted to 34.9 and 43.5 tons per square inch (55 to 69 kilograms per square millimeter), the elongation 7 to 19.5 per cent., contrac-

tion 12 to 45 per cent. on the sectional area.

The next beam, forming one of the cross girders of a bridge, was consecutively weighted till 478 rails had been placed on the platforms, and a tension had been reached of 21.6 tons per square inch (34 kilograms per square millimeter), without any alarming symptom being observed; the actual surpassed the calculating deflection, however, to a considerable extent. As soon as the total load, amounting to 144.8 tons (147,034 kilograms), had been imposed, and the tension had attained 22.9 tons per square inch (36 kilograms per square millimeter), the girder broke in two with a loud report. A rent in a lower angle-bar and a crack in the vertical web were discovered. The rent of the web-plate showed a fine fibrous fracture. This was the first experiment in which a total fracture occurred before warning snaps or reports were heard.

The dimensions of the cross girders had been calculated on the understanding that the extreme lamina were not to be strained beyond 6.34 tons per square inch (10 kilograms per square millimeter). The four steel girders tested at Dortmund broke when the calculated strain amounted to three and a-half times this tension. The ultimate strength of the steel was found to be over 38.1 tons per square inch (60 kilograms per square millimeter). Whereas, wrought-iron girders bear a load in the center without breaking or showing signs of shearing in the rivets, till the calculated tension in the extreme lamina approaches the limit of absolute strength; riveted steel beams break when the calculated strain reaches only half that due to the direct tenacity of the steel.

The results of the steel tests thus proved very disappointing. The different authorities on iron and steel manufacture declared that they had encountered phenomena which they could not explain, and it was determined to extend the experiments by means of some rejected girders of larger dimensions, which could be cheaply obtained. These were made of soft steel, of hard steel, and of wrought-iron, and it was also determined to ascertain the difference between girders bolted and riveted together. Accordingly, the following beams were experimented on: Twenty longitudinal girders intended for the bridge across the River Waal at Nymegen. The component parts of three of these girders were annealed before riveting, while two of the girders were not riveted, but bolted. Three cross-girders, three riveted girders of hard steel of the same dimensions as the longitudinals; three riveted girders of soft steel as above; three riveted iron girders as above.

For hard steel, a minimum resistance against tension of 47.6 tons per square inch (75 kilograms per square millimeter) was prescribed, and an elongation on fracture of at least 14 per cent. The requirements for soft steel were a maximum resistance to tension of 31.7 tons per square inch (50 kilograms per square millimeter), and an elongation of fracture of not less than 25 per cent. During the investigation, the question arose as to whether it would be practicable to anneal the riveted steel girders without injuring them. From the steel manufacturers in Westphalia no satisfactory answer could be obtained, consequently an investigation into this important matter became necessary, and one of the pieces of a girder broken in testing was used. It had a length of 13 ft. 6 in. (4,128 millimeters), and was not much deformed. On the top and bottom flange plates center lines were marked, and the width was measured on each side of these at distances 10 in. (25 centimeters) apart. All rivets were proved by means of a hammer and found perfectly tight. The girder was then laid on its side in a roomy annealing furnace, which had been heated for thirty-six hours, and was considered to have attained a temperature of 1,112° Fahrenheit (600° C.). Care was taken to prevent sagging by packing with stones. The furnace was opened for about twenty minutes, while the girder was inserted and packed. To prevent unequal cooling, the furnace was fired for five minutes after closing the doors, after which all openings were bricked up, and all cracks and joints were thoroughly luted with clay. These operations occupied forty-five minutes. The girder was left for sixty hours in the furnace, and was by that time completely cooled. It was then taken out and laid on the supports, on which it had rested during the marking of the center lines.

The girder proved to be warped over its full length; the top and bottom flange-plates were bent, and deviated respectively $20\frac{1}{8}$ in. (51 millimeters), and $5\frac{1}{8}$ inches (16 millimeters) from the original center line. The web was buckled in several places. The rivets were again tested by the hammer and found tight. On cutting off one of the rivet heads a slight layer of dust was found between the plate and the rivet head. With other rivet heads this phenomenon was not observed. The red lead, with which the girder had been painted, was partly burned, and partly remained in flakes adhering to the metal. The deformations were so great and numerous that it was considered as demonstrated that, even if fixed or strutted during annealing, no satisfactory results could be expected.

The results of the investigations are collected in tables, and represented graphically.

It will be seen, with regard to the wrought-iron girders, that the deflection increased in direct proportion to the load, till a tension in the extreme lamina of 16.6 to 17.1 tons per square inch (26 to 27 kilograms per square millimeter) was reached. This rate of deflection did not cease when the girder was again submitted to test, after having been previously loaded up to a tension of 19 tons per square inch (30 kilograms per square millimeter), and then unloaded, and a permanent set was observed of $\frac{5}{16}$ inch (4.18 millimeter). Up to this limit the deflections of the three girders agree very closely. At 17.1 tons per square inch (27 kilograms per square millimeter) the deflections were equal to those calculated, but beyond this limit the first exceeded the last in increasing measure. At 11.4 tons per square inch (18 kilograms per square millimeter) a slight permanent set (0.3 millimeter) was observed; this increased a little (to 1.08 millimeter), with a tension of 15.9 tons per square inch (25 kilograms per square millimeter), to $\frac{5}{16}$ inch (4.18 millimeters), with a tension of 19 tons per square inch (30 kilograms per square millimeter); and to $\frac{8}{8}$ inch (10 millimeters), and $1\frac{5}{16}$ inch (49 millimeters) with 24.12 tons per square inch (38 kilograms per square millimeter). The three girders resisted perfectly till a tension of 19.7 tons per square inch (31 kilograms per square millimeter) was imposed, but soon after some rivet-heads in the middle of the girders began to manifest displacement, which increased with the tension, the rivets gradually cutting into the flange-plates and webs. With 22.2 tons per square inch (35 kilograms tension per square millimeter) the compressed bottom flange,* which was supported laterally by the vertical side-stays, began to deflect laterally between the stays. In addition, the beginning of a rent was observed in two rivet-holes in the top flange plate of one of the girders. With 24.1 tons per square inch tension (38 kilograms per square millimeter), the limit of strength seems to have been reached. The little rent before mentioned was followed by a similar one in an adjacent rivet-hole of the flange-plate. When 24.6 tons per square inch (39 kilograms per square millimeter) tension was attained failure commenced, and a grinding rustling sound was heard repeatedly. At first the upper flange-plate opened. and was followed a few moments after by the second and third; the two angle-bars broke next, two dull reports were heard, the web-plate cracked, the rent widening slowly to $\frac{1}{16}$ inch (2 millimeters.

With a tension of 24.1 tons per square inch (38 kilograms per square millimeter), the three girders were visibly deformed. The top and bottom flanges showed lateral deflections. The plates of the bottom flanges between the rows of rivets were buckled vertically; the web-plates were bulged in many places. The pressure having been continued, the girder lost its symmetry, its resistance was destroyed, and the pressure-gauge indicated a continuously diminishing tension. The deflection did not decrease with the removal of the load. The top and bottom flanges showed considerable elongation and compression, amounting, in a length of four rows of rivets, or 1 foot (320 millimeters) to $\frac{7}{16}$ inch (11 millimeters) and $\frac{1}{8}$ inch (3 millimeters) repectively. Two vertical angle-bars secured to the web at a distance of 2.9 feet from each other (40 millimeters), receded from each other at the top $\frac{11}{16}$ inch (18 millimeters), and approached each other the same distance at the bottom.

Bending and tensile tests made on the

* Many of the girders were tested by hydraulic pressure applied upwards in the middle, hence the bottom flanges were often in compression.

several parts of the girders show a resistance against tension of 24.1 tons, and 25.4 tons per square inch (38 to 40 kilograms per square millimeter) an elongation at the point of fracture of 12 to 25 per cent., and a contraction of fractured area of 11 to 35 per cent.

Not a single unfavorable phenomenon was observed during these experiments on wrought-iron girders. The results corroborate sufficiently the accuracy of the calculations usual for determining their strength and deflection; they show that the admitted maximum tension gives a factor of safety of 5, that wrought-iron endures without detriment, shaping, drilling and riveting, and that, in being built up in the usual way, it makes a girder which leaves nothing to be desired in respect of strength and flexibility.

The steel girders, ranging in length from 17.6 feet (5,359 millimeters) to 20.3 feet (6,187 millimeters) show with tensions of 3.2 tons, 6.3 tons, 9.5 tons, 12.7 tons per square inch (per square millimeter of 5, 10, 15, and 20 kilograms) very similar deflections; the extreme variation amounted to only $\frac{1}{32}$ inch (0.8 millimeter) in one case. After unloading, the deflections nearly disappeared. In the case of three girders, 27.9 feet (8,500 millimeters) long, the deflections at the above indicated tensions showed variations ranging to $\frac{1}{8}$ inch (3.03 millimeters). The permanent sets, after a tension of 12.7 tons per square inch (20 kilograms per square millimeter) amounted to $\frac{1}{32}$ inch (1.01 millimeter). Also, with a tension of 13.3 tons per square inch (21 kilograms per square millimeter) in eighteen steel girders, the ratio between deflection and load remain constant, and the top flange-plate of one girder was torn with a tension of 11.4 tons per square inch (18 kilograms per square millimeter). Under a tension of 14 tons per square inch (22 kilograms per square millimeter) a snap was heard, but no crack was found. In another case one top angle-bar was completely, and the top flange-plate partly torn under a tension of 13.6 tons per square inch (20 kilograms per square millimeter). Again, a tension 15.2 tons per square inch (24 k ograms per square millimeter) was sufficient to destroy the top flange-plate and two angle bars of another girder. On reaching the supposed limit o elasticity, corresponding to 16.5 tons per square inch (26 kilograms per square millimeter) in the case of another beam, a report was heard, and the top flange-plate showed a tendency to move over the plate just underneath it.

After unloading, all the girders showed a small permanent set (varying from 0.06 millimeter to 1.41 millimeter). The deflections observed were, as a rule, smaller than those calculated in the fifteen lighter girders, but those in the three heavy girders were greater. No unfavorable symptoms were observed with a tension of 17.1 tons per square inch (27 kilograms per square millimeter), but under calculated tensions of 17.8 tons, 18.4 tons and 19 tons, up to 31.1 tons per square inch (28, 29, 30, etc., up to 49 kilograms per square millimeter) one or other of the girders was seen to be partly or wholly torn. The weakest girder succumbed at a tension of 20.3 tons per square inch (32 kilograms per square millimeter). Seven girders broke below 25.4 tons per square inch (40 kilograms per square millimeter); ten girders failed while the calculating strains were between 25.4 tons per square inch and 31.7 tons per square inch (40 kilograms and 50 kilograms per square millimeter). One single girder answered expectations, and showed no fissures or rents before the calculated strain in the extreme lamina amounted to 37.5 tons per square inch (59 kilograms per square millimeter). From each of the examined girders strips were taken and tested by bending and stretching. On the whole, the results were satisfactory. The resistance of tension in the direction of the fibers amounted to a maximum of 54.6 tons per square inch (86 kilograms per square millimeter), and to a minimum of 24.6 tons per square inch (39 kilograms per square millimeter). The greatest and smallest elongation observed were 25 and 5 per cent. The contraction on the sectional area varied from 49 to 11 per cent. Also the plates and bars bent cold gave satisfactory results.

The two experiments on steel girders put together with bolts contribute valuable information about the usual joining and riveting. The flange-plates, angle-bars, and web-plates of these girders were placed in position, and sufficiently held together by a few bolts to enable the

rivet-holes to be drilled right through the several thicknesses of metal. All stretching and compression was carefully avoided. The bolt-holes were drilled slightly conical and were fitted with bolts of the same shape. Washers were placed under the nuts, which were screwed home without any special strain. The two girders, under slowly increasing loads, showed regular deflections a little less than those calculated, and the deflections agreed well with those of the other steel girders, until a calculated strain of about 19 tons per square inch (30 kilograms per square millimeter) was reached. With continued increase of load, the deflections increased at a higher rate, and with a tenston of 22.9 tons per square inch (36 kilograms per square millimeter) the values exceeded those calculated. No snaps or rents were observed. The bottom flange of one of the girders showed incipient lateral deflection with a tension of 22.9 tons per square inch (36 kilograms per square millimeter), and this deformation slowly increased. The second girder, which was of greater length, remained longer in good condition, and only lost shape under a tension of 31.7 tons per square inch (50 kilograms per square millimeter). The deformations were greater and more irregular than those of the iron girders described before. Whether these more favorable results were owing to bolting instead of riveting cannot be decided with certainty. The results of the following six experiments seem to demonstrate that riveting does not necessarily cause harm. Six Bessemer steel bars $\frac{3}{16}$ inch (49 millimeters) thick and $2\frac{9}{16}$ inch (6 8 millimeters) wide were drilled through in the middle with two holes $\frac{13}{16}$ inch (21 millimeters in diameter). One of the holes was then filled with a steel rivet in the usual way. The bars were then tested for tension, and they all broke through the hole not riveted with a tension of 39.4 tons to 40 tons per square inch (62 to 63 kilograms per square millimeter). In the vicinity of the bolts not a vestige of splitting or rending could be found.

The annealing of the different parts of the girders before riveting did not answer expectations, the tests being, in fact, the least satisfactory. The top cover-plate and angle-bars of the three girders were torn with a tension of but 9.5 tons, 10.8 tons, and 12.7 tons per square inch (15 kilograms, 17 kilograms, and 20 kilograms per square millimeter). The tension of 3.2 tons per square inch (5 kilograms per square millimeter), had barely been reached in one of the girders when the deflection exceeded the calculated quantity. In the two other girders, this took place with a tension of about 14 tons per square inch (22 kilograms per square millimeter). The girders broke with a calculated tension of 14.6 tons, 16.5 tons, and 17.8 tons per square inch (23 kilograms, 26 kilograms, and 28 kilograms per square millimeter), after several premonitory signs of failure. No explanation has been given for these exceptionally unfavorable results. The annealing was performed in the usual manner and with all care. The tests were made during summer. The steel was of ordinary quality. The strips taken from the web plates of the broken girders after the experiments gave, on being tested, an ultimate strength of 32.4 tons and 33.0 tons per square inch (51 kilograms, 52 kilograms per square millimeter), those taken from the cover plates resisted a tensile strain of 29.2 tons, 31.7 tons, and 34.9 tons per square inch (46 kilograms, 50 and 55 kilograms per square millimeter). The elongations before fracture varied between 8 and 21 per cent. with one exception, when a cover-plate seemed to have been burned. The contraction on the sectional area amounted to from 27 to 41 per cent. The metal was generally granular on the fractured surface, but could be bent cold in a satisfactory manner.

The experiments on the three hard steel girders gave surprisingly favorable results. The deflections agreed completely, and increased uniformly with the load, remaining always a little below that calculated until an estimated strain of 34.9 tons per square inch (55 kilograms per square millimeter) was reached in the extreme fibers, and with this tension the two upper angle-bars of one of the girders broke. With an increased load, this beam broke at a tension of 43.2 tons per square inch (68 kilograms per square millimeter). The second girder tore, without previous damage, when the calculated strain amounted to 37.5 tons per square inch (59 kilograms per square

millimeter). It is remarkable that the top flange-plate showed a rent of $\frac{5}{16}$ inch (8 millimeters) wide, while in the web-plate only a small fissure could be found near one of the rivet-holes. In these three girders no motion of the rivets or cutting into the plates whatever took place. The third girder withstood a tension of 43.2 tons per square inch (68 kilograms per square millimeter); the experiment had then to be stopped, owing to signs of warping.

Strips taken from these three hard steel girders gave a resistance against tension of from 51.4 tons to 54.6 tons per square inch (81 kilograms to 86 kilograms per square millimeter), an elongation before fracture of from 9 to 15 per cent., a contraction of from 24 to 36 per cent.

It must be borne in mind that the steel in these girders was made purposely for the experiment, that great trouble was experienced in the manufacture before the material satisfied the different requirements, and that, therefore, it cannot be considered as a fair trading specimen, nor does it compare favorably with wrought-iron. When the wrought-iron girders were loaded till the strain in the extreme lamina amounted to 86 per cent. of the ultimate strength, or to 80 per cent. of the tensional resistance, deformation, indicating the approach of the limit of endurance, began to show, and failure did not occur suddenly, but by gradual yielding.

In the steel girders, fracture occurred suddenly, when the strains reached 73 per cent. of the ultimate strength and 66 per cent. of the extreme resistances to tension. The power of resistance beyond this point was of small value.

The deflection of the iron and the hard steel girders was equal until a strain of 16.5 tons per square inch (26 kilograms per square millimeter) was reached. Above this limit the deflection in the iron girders was the greater.

On the experiments on three soft steel girders, the following remarks may be made. The girders show deflections uniformly increasing with the load, until a strain of 12.7 tons per square inch (20 kilograms per square millimeter) was reached. After unloading, the permanent set was very slight (from 0.66 millimeter to 0.76 millimeter). After 14 tons per square inch (22 kilograms per square millimeter), the observed deflections exceeded those calculated, and these differences increased rapidly with the load. With a strain of 17.8 tons to 18.4 tons per square inch (28 and 29 kilograms per square millimeter), local bulges and deformations began to show, and some displacement of rivet-heads was noticed. A considerable deformation of the bottom flanges and bulges in the web-plates followed shortly after. When a calculated strain of 22.2 tons per square inch (35 kilograms per square millimeter) had been reached, the girders were considerably deformed, and the readings of the hydraulic gauge indicated the collapse of the girders.

Test samples showed a resistance to tensional strain of from 26.7 tons to 31.1 tons per square inch (42 kilograms to 49 kilograms per square millimeter), an elongation of from 12 to 24 per cent., and a contraction on the sectional area of from 42 to 50 per cent.

Though these results are not unfavorable they are not so good as those obtained from iron girders. The deflections of the steel girders were greater, the deformations and bulgings originated at an earlier period and were more irregular. The material for these girders was also manufactured specially for these experiments.

[NOTE.—It cannot fail to strike the reader of the above abstract that the quality of steel used in experiments was very irregular, and quite different from steel used for structural purposes at the present time in this and other countries. —W. A.]

A NEW ALLOY OF ALUMINIUM.—The applications of aluminium are now considerable, and M. Bourbouze, a French physicist, has added to their number by employing an alloy of the metals with tin for the internal parts of optical instruments, in place of brass. The alloy he employs consists of ten parts of tin and 100 parts of aluminium. It is white like aluminium, and has a density of 2.85, which is a little higher than that of pure aluminium. It is, therefore, comparatively light, which is an advantage for apparatus where lightness is desired. It can be soldered as easily as brass, without special means, and it is even more unalterable than aluminium to reagents. The attention of electrical instrument makers should, therefore, be called to it, especially for apparatus of a portable character.

SPECIFIC GRAVITY OF LOW-CARBON STEEL.

By F. LYNWOOD GARRISON, F.G.S.

Transactions of the American Institute of Mining Engineers.

As the specific gravity of low-carbon steel seems to be attracting considerable attention as a means of determining the quality and value of the metal, I give here a few of the results of a long series of experiments recently made by me. The object of the experiments not requiring more than approximate correctness in the third place of decimals, the extreme precautions to obtain accuracy which are sometimes used in determining specific gravity were not observed. But each piece of metal was carefully cleaned to remove scale, rust, dirt, etc., thoroughly dried, and then weighed in air, all weighings being carefully repeated. The balance used was one of Troemner's finest, and sensitive to one-tenth of a milligram. Before weighing in distilled water, care was taken to remove, as far as possible, the air enclosed in the pores of the metal.

The pieces of metal were suspended by means of fine silk thread, a correction of course being made for the weight of the silk. Care was taken that the water in which they were weighed should be always at the same level, and, as far as possible, at the same temperature.

The determinations were made upon the following samples:

1. Clapp-Griffiths steel bolt, 3 inches long and $\frac{1}{4}$ inch diameter, containing 0.08 carbon and 0.36 phosphorus.

2. Clapp-Griffiths steel bolt, 5 inches long and $\frac{1}{2}$ inch diameter, containing 0.08 carbon and 0.50 phosphorus.

3. Bessemer steel bolt, 3 inches long and $\frac{1}{4}$ inch diameter, containing 0.08 carbon.

4. Bessemer screw, containing 0.10 carbon.

5. Bessemer screw, containing 0.10 carbon.

6. Wrought-iron bolt, 6 inches long and $\frac{1}{2}$ inch diameter.

7. Wrought-iron bolt, 5 inches long and $\frac{5}{8}$ inch diameter.

No. 1 was divided into three parts, head, shaft, and nut. No. 2 was similarly divided, but the shaft was further divided transversely into five sections, each an inch long. No. 3 was divided like No. 1. Nos. 4 and 5 were each divided into head and one-inch sections of shaft. No. 6 similarly furnished head, six sections, and nut. No. 7. head, five sections, and nut. The specific gravity of each of these parts was determined separately, with the following results:

No.	1.	2.	3.	4.	5.	6.	7.
Head	7.822	7.886	7.800	7.796	7.759	7.705	7.638
Shaft, or 1st section	7.849	7.800	7.853	7.785	7.758	7.669	7.568
2nd section	.....	7.799	.....	7 859	7.813	7.676	7.556
3d section	.....	7.834	.....	.....	7.832	7.662	7.575
4th section	.....	7.834	.....	.....	.....	7.667	7.577
5th section	.....	7.836	.....	.....	.....	7.622	7.569
6th section	.....	.....	.....	.....	.....	7.625	.....
Average of head and shaft	7.8350	7.8315	7.8269	7.8133	7.7905	7.6609	7.5805
Nut	7.670	7.600	.....	.....	.....	7.584	7.640

The nuts were excluded from the above averages as probably manufactured from different pieces of metal.

It seems from the above that the density of the metal is considerably affected by shop-manipulations; for, as will be noticed in the case of the large Clapp-Griffiths steel bolt and the Bessemer steel

screws, the specific gravity is greater at the heads and at those parts on which the threads are cut. This sudden alteration in density can hardly be accidental, and must be caused by the pressure exerted in cutting the threads and forming the heads pushing the metal fibers closer together and thus decreasing the size and number of air cavities between them.

But so far as the screw-threads are concerned, the contrary seems to be the case with the wrought-iron bolts; for it will be noticed, their density gradually decreases from the head down. And in this respect No. 3 also is anomalous. It will be noticed, moreover, that my results are considerably below the figure of 7.854, adopted by Mr. Miller in his paper on this subject (*Transactions*, vol. xiv., p. 583), for boiler-plate steel containing 0.14 carbon.

ELECTROMOTORS FOR RAILWAYS.

From "Industries."

We have drawn attention to the question of electrically-propelled trains on railways, and pointed out that there were three great difficulties which must be overcome before electric railways can come into general use. The greatest of these difficulties is that of the conductors. We must generate the electric current at some fixed points situated in proximity to the line, and we must convey it to the train by means of a conductor fixed along the line, and so arranged that a metallic contact piece attached to the train and sliding along the conductor establishes at all times electrical connection between the generating dynamo and the motors in the train. Now, if the distance between the two is considerable, large portion of the electrical energy contained in the current is wasted in the conductor itself, and little remains to do useful work in the train. It is true that we can reduce this waste by making our conductor of very large cross section, and employing copper for it, which conducts electricity very freely; but in so doing we increase the first outlay too much. We can also reduce the waste by working with a comparatively small current of very high electromotive force. An experiment in this direction has lately been made by M. Marcel Deprez, who attempted to transmit power over a distance of 35 miles by means of an electric current of close upon 6,000 volts electromotive force. Practically, the experiments were a total failure, and this is mainly due to the high electromotive force employed. At the present moment, no electrical engineer would consider it safe to employ for transmission of power more than 1,000, or at the outside 1,500 volts, and at that pressure the limit of economical working is only a few miles. An electric railway of several hundred miles in length would therefore have to be fed with current from a large number of generating stations placed along the line every few miles, and the outlay for buildings and plant would in this case be excessive. It must also be borne in mind that where the current has to be generated by steam power, which in flat countries would always be the case, the total coal bill for the electrically-worked line would be about twice as heavy as it for ordinary locomotive traction, because the double conversion of mechanical energy into current, and back into mechanical energy, entails considerable loss. To fix ideas, let us suppose we have a tolerably level line which is to be worked by electricity, and that with the pressure of 1,000 volts, which we consider safe, we can transmit power economically to a distance of five miles. In this case, the distance from one generating station to the other would have to be about ten miles. As the train travels along the line, one station after another will be called upon to supply it with power, each station becoming idle when the train has passed beyond its reach. But if the traffic can be so arranged that the interval between successive trains is less than the time required to travel ten miles,

the machinery at the generating stations will never run idle; and beyond the usual reserve for cases of accident, no more power need be supplied than is actually represented by the total number of trains running simultaneously. This would be the case on a metropolitan railway, where trains, especially if short and provided with ample starting power, could succeed each other at intervals of one or two minutes. It would be perfectly safe to work such a line electrically at a pressure of 300 to 400 volts, and if the generating stations were placed every half mile or every mile along the line, the aggregate power which would have to be provided in these stations, would not materially exceed the power represented by the total number of locomotives which would otherwise have to be used to work the same line on the train system. In this case, the cost of the plant necessary for generating the current and the working expenses would not be disproportionate, if compared to the power actually utilized on the line. But if the line be very long, and the traffic comparatively light, the cost of the generating plant would be excessive, and electric traction, with power derived from fixed steam engines, and conveyed to the trains by conductors, could under no circumstances replace ordinary locomotive traction. We have spoken above of the difficulty of transmitting the current from the dynamo to the train, and we have shown how this difficulty limits the application of electric traction to short lines with very heavy traffic. There is, however, another alternative, and this consists in having no conductor at all, and in working the motors by means of secondary batteries carried in the train. No experiments on a large scale have as yet been undertaken to show whether this system is or is not commercially feasible. A few tramcars have in this and some continental countries been tried, which were propelled by secondary batteries and electromotors; but no railway has yet been worked on this plan. It is quite possible that, as accumulators are improved, they may be used with advantage on long level lines; and if water power be available for working the charging dynamo, the system may, even in point of economy, be found to compete successfully against steam locomotives.

We spoke in the beginning of this paper of three great difficulties which stand in the way of electric propulsion. The greatest, that of the conductor, has been at length discussed. The other two are, first, the excessive weight of electromotors, and secondly the difficulty of efficient and economical regulation of speed. When speaking of the weight of a motor per horse-power, it is always necessary to take into consideration also its speed, total power, and efficiency. It will be self-evident that the weight per horse-power will be the smaller, the quicker we arrange the motor to run, and the more we press it electrically, regardless of efficiency. But this is not a satisfactory way of reducing dead weight. What we want is a motor of high efficiency (at least 85 per cent.), moderate speed, and little weight. Now, these conditions are to a certain extent conflicting. There are motors in the market which give over 90 per cent. efficiency; but their speed is comparatively high, and they weigh from 2 to 2½ cwt. per horse-power. On the other hand, motors can be had which only weigh 60 lbs. per horse-power; but their efficiency is only about 60 per cent., and their speed excessively high in comparison with the power given out. It will be clear that the larger the motor the lower should be its speed. Thus a 5-horse motor running at 1,000 revolutions a minute, must be considered to be of moderate speed in comparison with a 10-horse motor running at 900 revolutions a minute. Yet even the speed of the former is inconveniently high, because it necessitates a complicated speed-reducing gear if applied to the axle of a railway coach. If motors could be designed weighing about 50 lb per horse-power, and of sufficiently low speed to be applied direct to the axle of railway wheels, a great step would have been taken in the development of electric railways. Another very necessary improvement is, some device by which the speed and power of electromotors can be varied at will, without wasting power by the introduction of artificial resistances. Such a device would be equivalent to the expansion gear in a steam engine, and would be necessary, not only for economic reasons, but also for the purpose of having the speed of the electric train under as perfect control as that

of an ordinary train drawn by a steam locomotive. We recommend these considerations to those of our readers who are practical electricians. The man who solves these problems will be sure to benefit his profession generally, and to reap himself large benefits from his invention.

ON NEW APPLICATIONS OF THE MECHANICAL PROPERTIES OF CORK TO THE ARTS.

A Paper read at the Royal Institution of Great Britain by WILLIAM ANDERSON, M. Inst., C.E., M.R.I.

From "Nature."

It would seem difficult to discover any new properties in a substance so familiar as cork, and yet it possesses qualities which distinguish it from all other solid or liquid bodies, namely, its power of altering its volume in a very marked degree in consequence of change of pressure. All liquids and solids are capable of cubical compression, or extension, but to a very small extent; thus, water is reduced in volume by only 1/2000 part by the pressure of one atmosphere. Liquid carbonic acid yields to pressure much more than any other fluid, but still the rate is very small. Solid substances, with the exception of cork, offer equally obstinate resistance to change of bulk; even india-rubber, which most people would suppose capable of very considerable change of volume, we shall find is really very rigid.

I have here an apparatus for applying pressure by means of a lever. I place a piece of solid india-rubber under the plate and you see that I can compress it considerably by a very light pressure of my finger. I slip this same piece of india-rubber into a brass tube, which it fits closely, and now you see that I am unable to compress it by any force which I can bring to bear. I even hammer the lever with a mallet, and the blow falls as it would on a stone. The reason of this phenomenon is, that in the first place, with the india-rubber free, it spread out laterally while being compressed longitudinally, and consequently the volume was hardly altered at all; in the second case, the strong brass tube prevented all lateral extension, and because india-rubber is incapable of appreciable cubical compression, its length only could not be sensibly altered by pressure.

Extension, in like manner, does not alter the volume of india-rubber. In this glass tube is a piece of solid round rubber which nearly fills the bore. The lower end of the rubber is fixed in the bottom of the tube, and the upper end is connected by a fine cord to a small windlass, by turning which I can stretch the rubber. I fill the tube to the brim with water, and throw an image of it on to the screen. If stretching the rubber either increases or diminishes its volume, the water in the tube will either overflow or shrink in it. I now stretch the rubber to about three inches, or one-third of its original length, but you cannot see any appreciable movement in the water-level, hence the volume of the rubber has not changed.

Metals when subjected to pressures which exceed their elastic limits, so that they are permanently deformed, as in forging or wire-drawing, remain practically unchanged in volume per unit of weight.

I have here a pair of common scales. To the under sides of the pans I can hang the various specimens that I wish to examine; underneath these are small beakers of water which I can raise or lower by means of a rack and pinion. Substances immersed in water lose in weight by the weight of their own volume of water; hence if two substances of equal volume balance each other in air, they will also balance when immersed in water, but if their volumes are not the same, then the substance having the smaller volume will sink, because the weight of water it displaces is less than that displaced by the substance with the larger volume. To the scale on your left hand is suspended a short cylinder

of ordinary iron, and to the right-hand scale a cylinder of ordinary copper. They balance exactly. I now raise the beakers and immerse the two cylinders in water; you see the copper cylinder sinks at once, and I know by that that the copper has a smaller volume per pound than iron, or, as we should commonly say, it is heavier than iron. I now detach the copper cylinder, and in its place hang on this iron one, which is made of the same bar as its fellow cylinder, but forced, while red hot, into a mould by a pressure of sixty tons per square inch, and allowed to cool under that pressure. The two cylinders balance, as you see. Has the volume of the iron in the compressed cylinder been altered by the rough treatment it has received? I raise the beakers, immerse the cylinders, the balance is not destroyed; hence we conclude that although the form has been changed the volume has remained the same. I substitute for the hot compressed cylinder one pressed into a mould while cold, and held there for some time, with a load of sixty tons per square inch; the balance is not destroyed by immersion, hence the volume has not been altered. I can repeat the experiments with these copper cylinders and the result will be found the same. Extension also is incapable of appreciably altering the density of metals. I attach to the scales two specimens of iron taken from a bar which had been torn asunder by a steady pull. One specimen is cut from the portion where it had not been strained, and the other from the very point where it had been gradually drawn out and fractured. The specimens balance, I immerse them, you see the balance is not destroyed; hence the volume of the iron has not been changed appreciably by extension.

But cork behaves in a very different manner. I place this cylinder of cork into just such a brass tube as served to restrain the india-rubber and apply pressure to it in the same way; you see I can readily compress the cork, and when I release it it expands back to its original volume: the action is a little sluggish, on account of the friction of the cork against the sides of the tube. In this case, therefore, a very great change in the volume of the material has been easily effected.

although solids evidently do not change sensibly in bulk, after having been released from pressures high enough to distort them permanently, yet, while actually under pressure, the volumes may have been considerably altered. As far as I am aware, this point has not been determined experimentally for metals, but it is very easy to show that india-rubber does not change.

I have here some of this substance, which is so very slightly lighter than water, that, as you see, it only just floats in cold water but sinks in hot. If I could put it under considerable pressure while afloat in cold water, then, if its volume became sensibly less, it ought to sink. In the same way, if I load a piece of cork and a piece of wood so that they barely float, if their volumes alter they ought to sink.

In this strong upright glass tube I have, at the top, a piece of india-rubber, immediately below it a piece of wood, and below that a cork; the wood and the cork are loaded with metal sinkers to reduce their buoyancy. The tube is full of water, and is connected to a force-pump, by means of which I can impose a pressure of over 1,000 lbs. per square inch. The image of the tube is now thrown on the screen and the pressure is being applied. You see at once the cork is beginning to shrink in all directions, and now its volume is so reduced that it is incapable of floating, and sinks down to the bottom of the tube. The india-rubber is absolutely unaffected, the wood does contract a little, but not sufficiently to be visible to you or to cause it to sink. I open a stop-cock and relieve the pressure; you see that the cork instantly expands, its buoyancy is restored, and it floats again. By alternately applying and taking off the pressure I can produce the familiar effect so well known in the toy called "the bottle imps." It is this singular property which gives to cork its value as a means of closing the mouths of bottles. Its elasticity has not only a very considerable range, but it is very persistent. Thus in the better kind of corks used in bottling champagne and other effervescing wines, you are all familiar with the extent to which the corks expand the instant they escape from the bottles. I have measured this expansion, and find it to amount to an increase of volume of 75 per cent., even after the corks have been kept in a

state of compression in the bottles for ten years. If the cork be steeped in hot water, the volume continues to increase till it attains nearly three times that which it occupied in the neck of the bottle.

When cork is subjected to pressure, either in one direction, as in this lever press, or from every direction, as when immersed in water under pressure, a certain amount of permanent deformation or "permanent set" takes place very quickly. This property is common to all solid elastic substances when strained beyond their elastic limits, but with cork the limits are comparatively low. You have, no doubt, noticed in chemists' and other shops that, when a cork is too large to fit a bottle, the shopkeeper gives the cork a few sharp bites, or, if he be more refined, he uses a pair of specially-contrived pincers; in either case he squeezes the cork beyond its elastic limits, and so makes it permanently smaller. Besides the permanent set, there is a certain amount of what I venture to call sluggish elasticity—that is, cork on being released from pressure, springs back a certain amount at once, but the complete recovery takes an appreciable time.

While I have been speaking, a piece of fresh cork, loaded so as barely to float, has been inserted into the vertical glass pressure tube. I apply a slight pressure, you see the cork sinks. I release the pressure, and it rises briskly enough. I now apply a much higher pressure for a moment or two. I release it, and the cork will either not rise at all, or will do so very slowly; its volume has been permanently altered; it has taken a permanent set.

In considering the properties of most substances, our search for the cause of these properties is baffled by our imperfect powers and the feeble instruments we possess for investigating molecular structure. With cork, happily, this is not the case; an examination of its structure is easy, and perfectly explains the cause of its peculiar and valuable properties.

All plants are built up of minute cells of various forms and dimensions. Their walls or sides are composed chiefly of a substance called cellulose, frequently associated with lignine, or woody matter, and with cork, which last is a nitrogenous substance, found in many portions of plants, but is especially developed in the outer bark of exogenous trees, that is, trees belonging to an order, by far the most common in these latitudes, the stems of which grow by the addition of layers of fresh cellulose tissue outside the woody part and inside the bark. Between the bark and the wood is interposed a thin fibrous layer, which, in some trees, such as the lime, is very much developed, and supplies the bass matting with which all are familiar. The corky part of the bark, which is outside, is composed of closed cells exclusively, so built together that no connection of a tubular nature runs up and down the tree, although horizontal passages radiating towards the woody part of the tree are numerous. In the woody part of the tree, on the contrary, and in the inner bark, vertical passages or tubes exist, while a connection is kept up with the pith of the tree by means of medullary rays. In one species of tree, known as the cork oak, the corky part of the bark is very strongly developed. I project on the screen the magnified image of a horizontal section of the bark of the cork oak; you see nine or ten bands running parallel to each other: these are the layers of cellulose matter that have been deposited in successive years. I turn the specimen, and you now see the vertical section with the radiating passages clearly marked.

The difference between the arrangement of the cells or tissue forming the woody part of the tree and the bark is easily shown. I have here three metal sockets, supported over a shallow wooden tray. Into them are fitted, first, a cork cut out of the bark in a vertical direction, next, a cork cut in a radial direction, and, lastly, a piece of common yellow pine. By means of my force-pump, I apply a couple of atmospheres of hydraulic pressure. I project an image of the apparatus on the screen, and you see the water has made its way through the wood and through the cork cut in the radial direction, while the cork cut in the vertical direction is impervious.

The cork tree, a species of evergreen oak, is indigenous in Portugal and along both shores of the Mediterranean. The diagram on the wall has been painted from a sketch obligingly sent to me by

Mr. C. A. Friend, the resident engineer of the Seville Waterworks, to whom I am also indebted for this branch of a cork tree, those acorns, this axe used in getting the cork, and for a description of the habits of the tree, its cultivation, and the mode of gathering the harvest.

The cork oak attains a height of 30 to 40 feet; it is not cultivated in any way, but grows like trees in a park. The first crop is not gathered till the tree is thirty years old, the next nine or ten years later; both these crops yield inferior cork, but at the third crop, gathered when the tree is fifty years old, the bark has attained full maturity, and after that will yield the highest quality of cork every nine or ten years. In the autumn of the year, when the bark is in a fit state, that is, for small trees, from three-quarters of an inch to one inch thick, and for larger ones up to one inch and a half, a horizontal cut is made by means of a light axe like the one I hold in my hand through the bark a few inches above the ground; succeeding cuts are made at distances of about a yard, up to the branches, and then along some of the larger ones, then two or more vertical cuts, according to the size of the tree, and the bark is then cut off by inserting the wedge-shaped end of the axe-handle. In making the cuts great care is taken to avoid wounding the inner bark, upon the integrity of which the health of the tree depends; but where this precaution is taken, the gathering of the cork does not in any way injure the tree.

After stripping, the cork is immersed for about an hour in hot water, it is dressed with a kind of spokeshave, then laid out flat and weighted, in order to take out the curvature; it is then stacked in the open air, without protection of any kind, for cork does not appear to be susceptible of receiving injury from the weather.

The minute structure of the bark is very remarkable. First, I project on the screen a microscopic section of the wood of the cork tree. It is taken in a horizontal plane, and I ask you to notice the diversity of the structure, and especially the presence of large tubes or pipes. I next exhibit a section taken in the same plane of the corky portion of the bark. You see the whole substance is made up of minute many-sided cells about 1 750 of an inch in diameter, and about twice as long, the long way of the cells being disposed radially to the trunk. The walls of the cells are extremely thin, and yet they are wonderfully impervious to liquids. Looked at by reflected light, if the specimen be turned, bands of silvery light alternate with bands of comparative darkness, showing that the cells are built on end to end in regular order. The vertical section next exhibited shows a cross section of the cells looking like a minute honeycomb. In some specimens large numbers of crystals are found. These could not be distinguished from the detached elementary spindle-shaped cells, of which woody fiber is made up, were it not for the powerful means of analysis we have in polarized light. I need hardly explain to an audience in this Institution that light passed through a Nicol prism becomes polarized, that is to say, the vibrations of the luminiferous ether are all reduced to vibrations in one plane, and consequently, if a second prism be interposed and placed at right angles to the first, the light will be unable to get through; but if we introduce between the crossed Nicols a substance capable of turning the plane of vibration again, then a certain portion of the light will pass. I have now projected on the screen the feeble light emerging from the crossed Nicols. I introduce the microscopic preparation of cork cells between them, and you see the crystals glowing with many colored lights on a dark ground.

Minute though these crystals are, they are very numerous and hard, and it is partly to them that is due the extraordinary rapidity with which cork blunts the cutting instruments used in shaping it. Cork-cutters always have beside them a sharpening-stone, on which they are obliged to restore the edges of their knives after a very few cuts.

The cells of the cork are filled with gaseous matter, which is very easily extracted, and which has been analyzed for me by Mr. G. H. Ogston, and proved to be common air. I have here a glass tube in which are some pieces of cork which have been cut into slices so as to facilitate the escape of the air. I connect the tube with an exhausted receiver and project the image on the screen; you see rising from the cork bubbles of air as

numerous, but much more minute than the bubbles which rise from sparkling wines; much more minute, because the bubbles you see are expanded to seven or eight times their volume at atmospheric pressure on account of the vacuum existing in the tube. The air will continue to come off for an hour or more, and from measurements made by Mr. Ogston I find that the air occluded in the cork amounts to about 53 per cent. of its volume. The facility with which the air escapes, compared with the impermeability of cork to liquids, is very remarkable.

I throw on the screen the image of a section cut from a cork which was kept under a vacuum of about 26 inches for five days and nights; aniline dye was then injected, and yet you see that the color has not more than permeated the outermost fringe of cells —those, in fact, which had been broken open by the operation of cutting the cork. By keeping cork for a very long time in an almost perfect vacuum, and then injecting dye, a slight darkening of the general color of a section of the cork may be noticed, but is very slight indeed. How, then, does the air escape so readily when the cork is placed *in vacuo?*

The answer is, that gases possess the property of diffusion; that is, of passing through porous media of inconceivable fineness. When two gases, such as hydrogen and air, are separated by a porous medium, they immediately begin to pass into each other, and the lighter gas passes through more quickly than the heavier.

I have here a glass tube, the upper end of which is closed by a thin slice of cork, the lower end dips into a basin of water. Some hours ago the tube was filled with hydrogen, which you know is about 14½ times lighter than air; consequently, according to the law of diffusion, it will get out of the tube through the cork quicker than the air can get in by the same means, and the result must be that a partial vacuum will be formed in the tube, and a column of water will be drawn up. You see that such has been the case, and we have thus proved that the cells of cork are eminently pervious to gases. The pores in the cell-walls appear, however, to be too minute to permit the passage of liquids.

I closed the end of a glass tube 11 mm. diameter, with a disk of cork 1.75 mm. thick, cut at right angles to the axis of the tree; I placed a solution of blue litmus inside the tube, and suspended it in a weak solution of sulphuric acid. Had diffusion taken place, both liquids would have assumed a red color, but after sixteen hours no change whatever could be detected. A like inertness was exhibited when the tube was filled with a solution of copper sulphate and suspended in a weak solution of ammonia; a deep blue color would have appeared had any intermixture taken place, and the same tube is before you immersed in ammonia and filled with red litmus solution. It has been in this condition since February 28, but no diffusion has taken place. A disk of wood 6 mm. thick under the same circumstances showed, after a couple of hours, by the liquids turning blue, that diffusion was going on actively. It is this property of allowing gases to permeate while completely barring liquids that enables cork to be kept in compression under water or in contact with various liquids without the air-cells becoming water-logged, and that makes cork so admirable an article for waterproof wear, such as boot-soles and hats; for, unlike india-rubber, it allows ventilation to go on while it keeps out the wet. The cell-walls are so strong, notwithstanding their extreme thinness, that they appear, when empty, to be able to resist the atmospheric pressure, for the volume of the cork does not sensibly diminish, even when all the air has been extracted. Viewed under very high power, cross-stays or struts of fibrous matter may be distinguished traversing the cells; these, no doubt, add to the strength and resistance of the structure.

From what you have seen you will have no difficulty in arriving at the conclusion that cork consists, practically, of an aggregation of minute air-vessels, having very thin, very water-tight, and very strong walls, and hence, if compressed, we may expect the resistance to compression to rise in a manner more like the resistance of gases than the resistance of an elastic solid such as a spring. In a spring the pressure increases in proportion to the distance to which the spring is compressed, but with gases the pressure increases in a much

more rapid manner; that is, inversely as the volume which the gas is made to occupy. But from the permeability of cork to air, it is evident that, if subjected to pressure in one direction only, it will gradually part with its occluded air by effusion, that is by its passage through the porous walls of the cells in which it is contained. This fact can be readily demonstrated by the lever press which I have used; for, if the brass cylinder containing the cork be filled with soap and water and pressure be then applied, minute bubbles will be found to collect on the surface, and their formation will go on for many hours.

On the other hand, if cork be subjected to pressure from all sides, such as operates when it is immersed in water under pressure, then the cells are supported in all directions, the air in them is reduced in volume, and there is no tendency to escape in one direction more than another. An india-rubber bag, such as this, distended by air, bursts, as you see, if pressed between two surfaces; but if an india-rubber cell be placed in a glass tube and subjected to hydraulic pressure, it is merely shriveled up; the strain on its walls is actually reduced.

To take advantage of the peculiar properties of cork in mechanical applications, it is necessary to determine accurately the law of its resistance to compression, and for this purpose I instituted a series of experiments of this kind. Into a strong iron vessel of 5½ gallons capacity I introduced a quantity of cork, and filled the interstices full of water, carefully getting out all the air. I then proceeded to pump in water, until definite pressures up to 1,000 pounds per square inch had been reached, and at every 100 pounds the weight of water pumped in was determined. In this way, after many repetitions, I obtained the decrease of volume due to any given increase of pressure. The observations have been plotted into the form of a curve, which you see on the diagram on the wall. The base-line represents a cylinder containing one cubic foot of cork divided by the vertical lines into ten parts; the black horizontal lines according to the scale on the left hand represent the pressures in pounds per square inch which were necessary to compress the cork to the corresponding volume. Thus to reduce the volume to one-half required a pressure of 250 pounds per square inch. At 1,000 pounds per square inch the volume was reduced to 44 per cent.; the yielding then became very little, showing that the solid parts of the cells had nearly come together, and this corroborates Mr. Ogston's determination that the gaseous part of cork constitutes 53 per cent. of its bulk. The engineer, in dealing with a compressible substance, requires to know not only the pressure which a given change of volume produces, but also the work which has to be expended in producing the change of volume. The work is calculated by multiplying the decrease of volume by the mean pressure per unit of area which produced it. The ordinates of the dotted curve on the diagram with the corresponding scale of foot-pounds on the right-hand side are drawn equal to the work done in compressing a cubic foot of cork to the several volumes marked on the base-line. I have not been able to find an equation to the pressure curve; it seems to be quite irregular, and hence the only way of calculating the effects of any given change of volume is to measure the ordinates of the curve constructed by actual experiment. As may be supposed, the pressures indicated by experiment are not nearly so regular and steady as corresponding experiments on a gas would be, and the actual form of the curves will depend on the quality of the cork experimented on.

The last point of importance in this inquiry relates to the permanence of elasticity in cork.

So far as preservation of elasticity during years of compression is concerned, we have the evidence of wine corks to show that a considerable range of elasticity is retained for a very long time. With respect to cork subjected to repeated compression and extension, I have very little evidence to offer beyond this, that cork which had been compressed and released in water many thousand times had not changed its molecular structure in the least, and had continued perfectly serviceable. Cork which has been kept under a pressure of three atmospheres for many weeks appears to have shrunk to from 80 to 85 per cent. of its original volume.

I will conclude this lecture by bringing

under your notice two novel applications of cork to the arts.

Before the lecture table stands a water-raising apparatus called a hydraulic ram. The structure of the machine is shown by a diagram on the wall. The ram consists of an inclined pipe, which leads the water from the reservoir into a chamber which terminates in a valve opening inwards. Branching up from the chamber is a passage leading to a valve opening outwards and communicating with a regulating vessel, which is usually filled with air, but which I prefer to fill with cork and water. Immediately beyond the inner valve is inserted a delivery pipe, which is laid to the spot to which the water has to be pumped, in this case to the fountain jet in the middle of this pan.

The action of the ram is as follows: The outer valve, which opens inward, is, in the first instance, held open, and a flow of water is allowed to take place through it down the pipe and chamber. The valve is then released, and is instantly shut by the current of water which is thus suddenly stopped, and, in consequence, delivers a blow similar to that produced by the fall of a hammer on an anvil, and just as the hammer jumps back from the anvil, so does the water recoil back to a small extent along the pipe.

During this action, first, a certain portion of water is forced by virtue of the blow through the inner valve, opening outwards, into the cork vessel, and so to the delivery pipe, and instantly afterwards the recoil causes a partial vacuum to form in the body of the ram, and permits the atmospheric pressure to open the outer valve and re-establish a rush of water as soon as the recoil has expended itself. In the little ram before you, this action, which it has taken so long to describe, is repeated 140 times in a minute.

The ram is now working. You hear the regular pulses of the valve, and you see a jet of water rising some 10 feet into the air. I throw the electric light on the water, and I ask you to notice the regularity of the flow. You can, indeed, detect the pulses of the ram in the fountain, but that is because I am only using a regulating vessel of the same capacity as that generally used for air, and you will recollect that 44 per cent. of the substance of cork is solid and inelastic. By closing a cock I can cut off the cork vessel from the ram; you see the regularity of the jet has disappeared; it now goes in leaps and bounds. This demonstrates that the elasticity of cork is competent to regulate the flow of water. When air is used for this purpose the air-vessel has to be filled, and, with most kinds of water, the supply has to be kept up while the ram is working, because water under pressure absorbs air. For this purpose a "sniff-valve" is a necessary part of all rams. It is a minute valve opening inwards, placed just below the inner valve; at each recoil a small bubble of air is drawn in and passed into the air-vessel. This "sniff-valve" is a fruitful source of trouble. Its minuteness renders it liable to get stopped up by dirt; it must not, of course, be submerged, and, if too large, it seriously affects the duty performed by the ram. The use of cork gets rid of all these difficulties, no sniff-valve is needed, the ram will work deeply submerged, and there is no fear of the cork vessel ever getting empty. The duty which even the little ram before you has done is 65 per cent., and larger ones have reached 80 per cent.

The second novel application of cork is for the purpose of storing a portion of the energy of the recoil of cannon, for the purpose of expending it afterwards in running them out.

The result of the explosion of gunpowder in a gun is to drive the shot out in one direction, and to cause the gun to recoil with equal energy the opposite way. To restrain the motion of the gun, "compressors" of various kinds are used, and in this country, for modern guns, they are generally hydraulic, that is to say, the force of recoil is expended in causing the gun to mount an inclined plane, and, at the same time, in driving a piston into a cylinder full of water, the latter being allowed to squeeze past the piston through apertures, the areas of which are either fixed or capable of being automatically varied as the gun recedes; or else the water is driven out of the cylinder through loaded valves. As a rule, the gun is moved out again into its firing position by its weight causing it to run down the inclined plane, up which it had previously recoiled. For naval pur-

poses, however, this plan is inconvenient, because the gun will not run out to windward if the vessel is heeling over, on account of the inclined plane becoming more horizontal, or even inclined in the reverse direction, and should the ship take a permanent list, from a compartment getting full of water, the inconvenience might be very considerable.

In land service guns, when mounted in barbette, the rising of the gun exposes it and the loading detachment more to the enemy's fire, and in both cases, when placed in ports or embrasures, the ports must be higher than if the gun recoiled horizontally, and will therefore offer a better mark to the enemy's fire, especially that of machine guns, while the sudden rise of the gun in recoiling imposes a severe downward pressure on the deck or on the platform.

To obviate these disadvantages I have contrived the gun-carriage a model of which is before you on the table, and a diagram of which on the wall illustrates the internal construction. The gun is mounted on a carriage composed of two hydraulic cylinders, united so as to form one piece. The carriage slides on a pair of hollow ways, and also on to a pair of fixed rams, the rear ends of which are attached to the piece forming the rear of the mounting. There are water passages down the axes of the rams, and these communicate through an automatic recoil-valve, opening from the cylinders, with the two hollow slides. There is a second communication between the cylinders and slides by means of a cock, which can be opened or shut at pleasure. The hollow slides are packed full of cork and water, the latter also completely filling the cylinders, rams, and various connecting passages.

By means of a small force-pump enough water can be injected to give the cork so much initial compression as will suffice to run the gun out when the slides are inclined under any angle which may be found convenient.

When the gun is fired, the cylinders are driven on to the rams, and the water in the cylinders is forced through the hollow rams into the cork and water vessels formed by the slides, and the cork is compressed still farther. When the recoil is over, the automatic recoil-valve closes, and the gun remains in its rearward position ready for loading.

As soon as loaded, the running-out cock is opened, the expansion of the cork drives the water from around it into the cylinders, and so forces the gun out.

If it be desired to let the gun run out automatically immediately after recoil, it is only necessary to leave the running-out cock open, and then the water forced among the cork by recoil returns instantly to the cylinders, and runs the gun out quicker than the eye can follow the motion.

I will now load the model and fire a shot into this strong steel cylinder, at the bottom of which is a thick layer of soft wood. I will close the running-out valve, so that the gun shall remain in the recoiled position. Sir Frederick Abel has kindly arranged some of his electric fuses specially to fit this minute ordnance, and I can fire the gun by means of a small electro-magnetic battery. The gun has now recoiled, and remains in its rear position. I load again, open the running-out cock, the gun runs out, and I fire without closing the cock. You see the gun has recoiled and run out instantly again.

The arrangement I have adopted may be made by using air instead of cork, but air is a troublesome substance to deal with; it leaks out very easily, and without showing any signs of having done so, which might readily lead to serious consequences. A special pump is required to make up loss by leakage.

The merit of cork is its extreme simplicity and trustworthiness. By mixing a certain proportion of glycerine with the water it will not freeze in any ordinary cold weather.

A Magnesium Torch.—At a recent meeting of the Pharmaceutical Society, a cylinder of magnesium 10 in. long was shown by Messrs. Hopkins and Williams. When produced in a dense and massive form, such as this, there is less tendency to rapid combustion when burning. Magnesium torches are now used in Germany for the illumination of mines. The cost of the metal is now about 30s. per pound.

WATER PURIFICATION—ITS BIOLOGICAL AND CHEMICAL BASIS.

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I.

Although the purification of water has received much attention during the past thirty years, it is only now that the complexity of this subject is beginning to be realized.

The earliest attempts to purify water had for their object simply the clarification of the liquid, *i.e.*, the removal of suspended particles visible to the naked eye.

In this purification there was no endeavor to remove dissolved matters, and suspended particles invisible to the naked eye were not then thought of. It cannot be doubted that, in most cases, this primitive conception of water-purification has still been retained, the sole idea of the operator being to produce a liquid clear and sparkling to the eye.

The advances of chemical science caused attention to be paid to the matters present in water in the state of solution, and more particularly to those of an organic nature. In the first place, it was supposed that organic substances were capable of imparting alteration and decay to other organic substances with which they were placed in contact; this being the theory of fermentation advanced by Liebig. Thus Liebig conceived that ordinary alcoholic fermentation was brought about not by the living and growing yeast, but by the dead yeast-cells undergoing decomposition. As long as this theory was the accepted doctrine of the day, it was not surprising to find chemists attaching great importance to the organic matter in water which analysis revealed, and which was known to have been derived from decomposing vegetable and animal substances with which the water had been in contact. It was naturally supposed that such decomposing organic matter in water would tend to set up putrefactive and other injurious changes in the digestive organs through which it passed.

The theory, or rather dogma, of fermentation enunciated by Liebig, was soon broken down by the classical researches of Pasteur, by whom it was shown that the processes of fermentation and putrefaction were due not to decomposing organic matter, but to living organisms, and that living organisms were also certainly the cause of some and probably of all zymotic diseases. Under these circumstances, the organic matter present in water came to be viewed in a different light, and instead of being regarded as in itself unwholesome, it could now only be taken as affording more or less evidence of the possible presence of organisms endowed with virulent properties. As it was further established beyond doubt, by bitter practical experience, that certain zymotic diseases—notably typhoid fever and cholera—could be communicated by means of sewage-polluted water, the chemical examination of water was prosecuted with a view of ascertaining the presence or absence of such contamination by means of the organic matter which the water was found to contain. Through refinement in the processes of chemical analysis it has, moreover, been rendered possible to discriminate with a very considerable degree of certainty between organic matter of vegetable, and that of animal origin. The detection of animal matter in water was not supposed to carry with it *ipso facto* the certainty of danger, but in the absence of any precise knowledge concerning those organisms which produce zymotic disease, the presence of such animal matter obviously indicated the possibility of danger.

It is thus seen that in this second stage of progressive knowledge, the purity of water was at first gauged merely from a chemical point of view, and that afterwards, through the researches of Pasteur and others, it came to be understood that chemical purity was really of less importance than biological purity; but owing to the absence of any satisfactory means

of examining waters biologically, the chemical standard was the only one by which they could be judged.

Under these circumstances, it was natural that means should be devised to render water as chemically pure as possible, on the assumption that the conditions which tended to improve the chemical quality would similarly affect it biologically. This is essentially the period of the late Rivers Pollution Commission, in which so many methods of water and sewage purification are fully discussed by the light of chemical analysis. In these discussions, the importance of the biological side of the subject is fully recognized, but owing to the absence of any reliable methods at that time, the examination was not pursued in this direction.

It is to the vastly improved methods of biological examination that the only great step which has been made in the knowledge of the purification of water since the researches of the last Commission is to be attributed. These methods of biological examination, which are largely due to the genius of Dr. Robert Koch, of Berlin, enable the merely chemical investigation of the subject of water purification to be supplemented in a manner that was never possible before.

This method of examination is based upon principles of such exquisite simplicity, that a very brief description will suffice to render it intelligible.

The microscopic living particles known as "micro-organisms," or "mycrophytes," which it is the object of a biological examination to study, possess such an astonishing power of rapid multiplication when they are placed in a medium fitted for their growth, that within a very short period of time it becomes impossible to form an opinion as to the number of original organisms from which the vast population is descended.

Thus, if such micro-organisms be distributed throughout a medium suitable for their multiplication, and if each individual organism be then immediately deprived of the possibility of movement, the number of colonies arising from the multiplication of these isolated individuals indicates the number of organisms introduced, whilst, by the nature of the colonies formed, the kinds of organisms of which the original importation consisted may be ascertained.

If the conditions here indicated can be complied with, it is obvious that all the means are at hand for determining the effect of any method of water-treatment upon these lowest forms of organic life. This imprisonment, so to speak, of each individual and its subsequent progeny, which is thus the key to the whole problem, can be readily effected by adding to a nutritive liquid, such as extract of meat, a sufficient quantity of gelatine to render the whole solid at the ordinary temperature. The process consists, in short, in taking a known volume, *e.g.*, 1 cubic centimeter of water, and mixing it with a quantity of such nutritive gelatine, that has been melted at the temperature of the hand, and then pouring the mixture upon a glass plate on which it sets in the course of a few minutes to a solid mass. The plate is placed under a glass cover, so as to protect it from dust, and is kept at a temperature of about 20° to 25° Centigrade. In the course of from three to five days the colonies, each originating from a single organism, attain such dimensions that they may be recognized and counted with the naked eye or by means of a microscope of low magnifying power.

It is thus evident that the purification of water must now be regarded from two distinct points of view—the chemical and the biological—and that whereas formerly the biological side was almost wholly of a speculative character, it is now nearly, if not quite as tangible as the chemical side. Thus, perhaps a concrete example will most clearly illustrate how the purification of water should be regarded. Supposing that water, derived from a source which is altogether unimpeachable as regards contamination with animal matters, is yet so highly impregnated with vegetable constituents as to be objectionable for drinking purposes, the question will arise how this water may be treated so as to render it suitable for domestic supply. In a case of this kind it is obvious that chemical purification will be of paramount importance, whilst the removal of organic life from the water will be of less pressing consequence. On the other hand, if water which is known to have received sewage matters is to be supplied for dietetic use, and if this water, as is so

often the case, is not objectionable on account of the absolute quantity of organic matter which it contains, but only because of the suspicious origin of a part of this organic matter, then it is evident that in the purification of such water the point to be taken primarily into consideration, is how the organic life it contains can be reduced to a minimum.

In estimating the value of such processes of purification, it has hitherto been customary to assume that those processes which effect the greatest chemical improvement in water may also be safely considered to be biologically the most excellent; and conversely, that those processes which effect little or no reduction in the proportion of organic impurity are not calculated to be of any service in removing organized matters.

In the experiments which the author has for some time been conducting on the removal of micro-organisms from water, the first results of which he communicated to the Royal Society in May, 1885, he has found that this assumed law, or at least its converse, is very far from being correct. Thus the author discovered that some materials were capable of filtering out all the organisms in water without appreciably altering its chemical composition.

The author's inquiry into the chemical and biological purification of water may be conveniently considered under four heads:

1. Purification by filtration.
2. Purification by agitation with solid particles.
3. Purification by precipitation.
4. Purification by natural agencies.

I. Purification by Filtration.

Until the method of water examination by gelatine-culture was devised, there were no available means by which the relative efficiency, for the removal of micro-organisms, of different filtering materials could be estimated on a quantitative basis.

The author has submitted to examination, as regards their efficiency in this respect, a number of filtering materials, employing in all cases equal thicknesses of the various substances, which were also prepared in the same state of division. The filtering stratum was constructed exactly 6 inches in depth, and the filtering material was, with a few exceptions, made to pass through a sieve of 40 meshes to the linear inch. The results obtained in these experiments were:

Filtering Material.	Efficiency.	Organisms per Cubic Centimeter.		Reduction per cent.	Approximate rate of filtration per square foot per hour.
		Unfiltered Water.	Filtered Water.		
					Gallons.
Ferruginous greensand (from Redhill, Surrey)	Initial	80	—	100.0	—
	After thirteen days' action	8,000	1,000	88.0	0.73
	After one month's action.	1,280	780	39.0	1.14
Animal-charcoal	Initial	Too numerous to count.	—	100.0	—
	After twelve days' action.	2,800	—	100.0	0.46
	After one month's action.	1,280	7,000	Increase 447.0	0.86
Iron sponge	Initial	80	—	100.0	—
	After twelve days' action	2,800	—	100.0	0.40
	After one month's action.	1,280	2	99.8	0.45
Brick-dust (pulverized red brick)	Initial	3,000	730	76.0	—
	After five weeks' action.	6,000	400	93.0	0.48
Coke	Initial	3,000	—	100.0	—
	After five weeks' action.	6,000	90	98.5	0.50

The author has made further experiments on the efficiency of coke as a filtering material. In these experiments the filters employed were of similar construction to those already described, but an aqueous extract of garden-soil was employed instead of urine-water.

Two similar filters (*a*) and (*b*) were submitted to examination, under conditions as similar as possible:

INITIAL EFFICIENCY (SECOND DAY).

Per cubic centimeter.

Unfiltered water.....26,000 organisms.
Filter (*a*)..... 0 "
Filter (*b*)..... 0 "

Reduction (*a*)=100 per cent.
" (*b*)=100 "

Per square foot per hour.

Approximate rate of filtration (*a*)=0.89 gallon.
" " " (*b*)=0.67 "

AFTER THREE WEEKS' ACTION (TWENTY-FIRST DAY).

Per cubic centimeter.

Unfiltered water .....2,230 organisms.
Filter (*a*)..... 339 "
Filter (*b*)..... 219 "

Reduction (*a*)=85 per cent.
" (*b*)=90 "

Per square foot per hour.

Approximate rate of filtration (*a*)=1.32 gallon.
" " " (*b*)=1.03 "

On comparing these latter experiments with those previously obtained, it will be seen that although the initial efficiency was in both cases the same, the greater rate of filtration which prevailed in the latter experiments caused the efficiency to deteriorate more rapidly, the filter (*a*), which was the most rapid, breaking down to a greater extent than the less rapid filter (*b*).

The unfiltered and filtered waters, respectively, were also submitted to chemical examination, at the time that the filters were exerting their greatest efficiency in the removal of micro organisms; the results are given in the following table, together with those obtained by the filtration of the same water through fine vegetable-charcoal, and through a mixture of fine and coarse vegetable-charcoal, respectively:

RESULTS OF ANALYSIS EXPRESSED IN PARTS PER 100,000.

	Unfiltered Water.	Water from Fine Coke		Water from Fine Wood Charcoal.	Water from Coarse and Fine Wood Charcoal.
		A.	B.		
Total solids	24.80	24.60	25.00	24.68	24.64
Organic carbon	0.144	0.118	0.107	0.090	0.098
Organic nitrogen	0.050	0.040	0.038	0.024	0.031
Ammonia	0	0	0	0	0
Nitrogen as nitrates and nitrites	0.190	0.209	0.202	0.221	0.217
Total combined nitrogen	0.240	0.249	0.240	0.245	0.248
Chlorine	1.9	1.9	1.9	1.9	1.9
Temporary hardness	11.3	11.3	11.3	12.5	12.3
Permanent hardness	5.6	5.6	5.6	4.6	4.6
Total hardness	16.9	16.9	16.9	17.1	16.9

These results show that filtration through coke exerts but an insignificant chemical action, even when the purification from a biological point of view is complete.

Vegetable-Charcoal.—The very favorable results obtained with coke led the author to investigate the filtering power of the still more porous vegetable or wood charcoal. This material was also

passed through the same sieve, and employed in filters of similar construction. In the first experiment urine-water was used, with the following results:

INITIAL EFFICIENCY (SECOND DAY).

	Organisms per Cubic Centimeter.
Unfiltered water	9,700
Water filtered through fine charcoal	0

Reduction=100 per cent.

Later experiments were made with an aqueous extract of soil, the following results being obtained:

INITIAL EFFICIENCY (SECOND DAY),

	Organisms per cubic centimeter.
Unfiltered water	2,898
After filtration through fine wood-charcoal	0

Reduction=100 per cent.

Approximate rate of filtration=0.22 gallon per square foot per hour.

AFTER ONE MONTH'S ACTION (TWENTY-NINTH DAY).

	Organisms per cubic centimeter.
Unfiltered water	2,230
After filtration through wood charcoal	107

Reduction=95 per cent.

Approximate rate of filtration=0·22 gallon per square foot per hour.

It is thus seen that the efficiency of the fine charcoal at the end of one month is less than that of the coke with the slow rate of filtration, but greater than that of the more rapid coke filters at the end of three weeks, the rate of filtration in the case of the charcoal being markedly less than in any of the coke experiments.

In order to obtain a more rapid charcoal filter, an intimate mixture was made of equal parts of coarse and of fine charcoal, the former having passed through a sieve of 9 wires by 30 wires to the square inch, and the latter through one of 40 meshes to the linear inch, and this was introduced into a glass tube, so as to form a stratum of filtering material 6 inches in depth. With this filter the following results were obtained:

INITIAL EFFICIENCY (SECOND DAY).

	Organisms per cubic centimeter.
Unfiltered water	26,000
Filtered through coarse and fine charcoal	0

Reduction=100 per cent.

Approximate rate of filtration=0·26 gallon per square foot per hour.

AFTER THREE WEEKS' ACTION (TWENTY-FIRST DAY).

	Organisms per cubic centimeter.
Unfiltered water	2,230
Filtered through coarse and fine charcoal.	506

Reduction=77 per cent.

Approximate rate of filtration=0·59 gallon per square foot per hour.

Thus with wood-charcoal, when the rate of filtration approaches that through coke, the improvement, from a biological point of view, is markedly less. The effect which this material has upon the chemical composition of the water, as exhibited in the above table, is greater than that of coke, but is also not very considerable.

It has generally been supposed that most filtering materials offer little or no barrier to micro-organisms, and that the latter are capable of passing without sensible obstruction through the pores of filters containing pulverized materials. These experiments, however, show that it is extremely simple to construct filters which shall possess the power of removing micro-organisms, in the first instance at least. This power is, moreover, possessed by substances which exercise scarcely any chemical action on the organic matter present in the water, *e.g.*, coke, vegetable-charcoal, and biscuit-porcelain, as well as by those which reduce both the organic and the mineral ingredients of the water to a very marked extent, like animal-charcoal and iron.

Especially noticeable is the case of vegetable-carbon, whether in the form of charcoal or of coke; this material has been generally regarded as of but little value for water purification, owing to its chemical inactivity, but as biological filters these substances occupy a high place, and owing to their cheapness and the facility with which they may be renewed, and profitably disposed of as fuel, they are, in the author's opinion, destined to be of great service in the purification of water.

These materials, coke and vegetable-charcoal, are also especially well fitted for use in breweries and distilleries, where it is so necessary to have a water which, though perfectly free from organic life, is at the same time free from antiseptic substances, such as iron, which militate against fermentation. Coke has already been used, at the author's suggestion, with marked success.

These experiments, however, show most distinctly the necessity of frequent renewal, even in the case of the best filtering materials, and this is a point which, unfortunately, is too often lost sight of.

Lastly, they furnish abundant confirmation of the principle which has been long known to waterworks engineers, viz, that which is gained in rapidity, is lost in efficiency, and *vice versa*.

II. Purification by Agitation with Sold Particles.

This method of water purification has recently been brought prominently before the public by Mr. W. Anderson, M. Inst. C.E., who has patented a process for agitating water with scrap-iron in a revolving cylinder. Some of the results obtained by this method have been brought before the Institution of Civil Engineers by Mr. W. Anderson and Mr. G. H. Ogston, Assoc. Inst. C.E. In this process, however, the purification is probably due almost entirely to chemical action, inasmuch as a portion of the iron passes into solution, and is subsequently precipitated in a settling-tank by contact with the air. This process is employed on a large scale at the Antwerp Waterworks, where it has superseded filtration through spongy iron; and on a large experimental scale it may be seen in operation at the Lee Bridge works of the East London Waterworks Company.

The author has not himself examined this particular method of purification, but he has made a number of experiments in order to ascertain whether, and to what extent, the organized matters in water may be removed by agitation with finely-divided solid particles of various kinds.

It appeared probable, from the results of the filtration-experiments already described, that organized substances might be largely removed by mere contact with finely-divided matter. A series of experiments was consequently undertaken with a view to ascertain to what extent this was the case, and in some instances the reduction was found to be much greater than could have reasonably been anticipated.

In these experiments water containing micro-organisms was shaken up for a definite length of time with a given quantity of the finely-divided matter, which was used in the same state of subdivision as in the filters already described. The water was then allowed to subside, and the clarified water submitted to examination, as soon as possible after complete subsidence had taken place, as it appeared probable that if the organisms were simply carried to the bottom by the subsiding particles without suffering any injury, they would rapidly again become distributed through the upper layers of water by multiplication. This supposition has been amply verified by experiment.

Agitation with Spongy Iron.—The water was shaken with one-tenth of its weight of this material for fifteen minutes. The water was allowed to subside for half-an-hour before examination.

	Organisms per cubic centimeter.
Untreated water contained	609
After fifteen minutes' agitation	63

Reduction=90 per cent.

On another occasion the water of the Thames, at Hampton, was shaken with spongy iron for fifteen minutes, with the following results:

	Organisms per cubic centimeter.
Thames water	155
After fiteen minutes' agitation	10

Reduction=93 per cent.

Agitation with Chalk.—Urine-water was shaken for fifteen minutes with one-fiftieth of its weight of chalk, and then allowed to subside for five hours:

	Organisms per cubic centimeter.
Untreated water	8,000
After agitation	270

Reduction=97 per cent.

Agitation with Animal-Charcoal.—Urine-water was shaken with one-fiftieth of its weight of animal-charcoal for fifteen minutes, and then allowed to subside for nearly five hours:

	Organisms per cubic centimeter.
Untreated water	8,000
After agitation	60

Reduction=99 per cent.

Agitation with Vegetable-Charcoal.—Water containing soil-extract was shaken with one-fiftieth of its weight of ordinary wood-charcoal for fifteen minutes, and was then allowed to subside for twenty-seven hours:

	Organisms per cubic centimeter.
Untreated water	3,000
After agitation	120

Reduction=96 per cent.

Agitation with Coke.—Urine-water was shaken with one-fiftieth of its weight of fine coke for fifteen minutes, and then allowed to subside for forty-eighty hours:

Untreated water.....Too numerous to be
After agitation with coke..None. [counted.
Reduction=100 per cent.

Further experiments made with water containing soil-extract have shown that this process of purification is unreliable, owing apparently to the numerous conditions which are necessary for its success. In some cases the number of organisms in the clear liquid was greatly increased. This being doubtless due to a re-ascension and multiplication of those which were at first carried down. Thus in one series of experiments the following results were obtained:

	Organisms per cubic centimeter.
Untreated water	3,000
After agitation with coke and twenty-six hours' subsidence	20,000

Further experiments of a similar nature were made, but less time (only five hours) was allowed for subsidence:

	Organisms per cubic centimeter.
Untreated water	655
After agitation with coke and five hours' subsidence	28

Reduction=96 per cent.

Thus, although a most remarkable purification may be accomplished by this simple process of agitation with the various substances specified, yet, owing to the uncertainty of its success, its efficiency cannot at present be relied on.

Water was also agitated with several other substances, such as china clay, brickdust, plaster of Paris, oxide of manganese, &c.; all of these, however, yielded unsatisfactory results.

The conclusion to be drawn from these experiments is that very porous substances like coke, animal and vegetable charcoal, are highly efficient in removing organized matter from water when the latter is exposed to their contact in agitation.

The removal of micro-organisms through the surface-attraction of suspended particles naturally leads to a consideration of what takes place when the suspended particles are generated in the water itself by precipitation.

III. Purification of Water by Precipitation.

As by far the most common and most important method of water purification dependent upon precipitation is the well-known Dr. Clark's process, the effect of this on organized matters was made the subject of special study. With this view the author has examined the process both in the laboratory as well as on the large scale as practiced by manufacturers and by water companies.

Laboratory Experiments.—For testing the efficiency of the process on the laboratory scale, three stoppered Winchester quart bottles were taken, and to each were added two liters of ordinary London (Thames) water, to which a convenient proportion of organisms had been imparted by the addition of urine water. To two of these bottles, 100 cubic centimeters of clear lime-water were added, this being calculated to remove 11.6 parts of carbonate of lime per 100,000 parts of the water. Each of these bottles was violently shaken, and the contents were then allowed to subside for eighteen hours. The bottle to which no lime-water had been added was tested without disturbing the precipitate, as was also the third bottle which had been left at rest in the same place as the other two. These tests showed the following numbers of organisms to be present in the water before and after treatment:

	Organisms per cubic centimeter.
Untreated water	85
After eighteen hours' rest	1,922
Water after treatment by Clark's Process and eighteen hours' subsidence.	42

Reduction on original=51 per cent.

In order to appreciate the value of the treatment by Dr. Clark's process, it is necessary that the treated waters should be compared not only with the original water, but also with the untreated water after eighteen hours' rest; for the latter obviously indicates what the condition of the water would have been at the time of examination, if no lime-water had been added. It appeared probable that, after the subsidence of the carbonate-of-lime precipitate had taken place, the organisms which had been carried down by the latter would again become distributed throughout the upper layers of the water. In order to ascertain whether this was the case or not, the same waters which had remained stoppered up and at rest, were again examined after the lapse of ten days. It was then found that the untreated as well as the softened waters contained immense numbers of organisms in their upper layers.

In another series of experiments car-

ried out under the same conditions, excepting that twenty-one instead of eighteen hours were allowed for the subsidence of the carbonate of lime, a reduction in the number of organisms amounting to 41 per cent. was obtained.

Experiments on an Industrial Scale.—It appeared to be of great interest to ascertain what results could be obtained by Dr. Clark's process on the large scale. For this purpose the process of softening as practiced at the Colne Valley Waterworks at Bushey, near Watford, was investigated, as well as the new modification of Dr. Clark's process, devised by Messrs. Gaillet and Huet, which was lately in operation at Mr. Duncan's Sugar Refinery, Clyde Wharf, Victoria Dock. The author is indebted to Mr. Verini, of the Colne Valley Waterworks, as well as to Mr. Duncan and Mr. Newlands, for their kindness in permitting him to carry out these experiments.

At the Colne Valley Waterworks, the hard water (see analyses given below) obtained from a deep well sunk into the chalk, is mixed with the requisite proportion of clear lime-water, and then allowed to settle in open tanks. The subsidence is so rapid that under favorable circumstances the upper layers of water are, after three hours' time, fit for distribution. On the occasion of the author's visit, however, boring operations were being carried on, and the water was in consequence milky, and the necessary subsidence after softening had to be increased to two days.

A perfectly representative sample of the water before softening could unfortunately not be obtained, and the number of organisms found in the untreated water is probably in excess of that which was present in the unsoftened water. The following results were obtained:

	Organisms per cubic centimeter.
Unsoftened water	322
Water after softening and two days' subsidence (from main)	4

Reduction=99 per cent.

In Gaillet and Huet's process as carried out at Mr. Duncan's, the water from an artesian well, sunk into the chalk below the London clay, is mixed with a suitable proportion of lime-water and caustic soda, the mixture being then made to pass upwards through a tower provided with oblique diaphragms, which accelerate the precipitation of the carbonate of lime. The passage through this tower occupies a period of about two hours. Samples of the water before and after treatment were examined, with the following results:

	Organisms per cubic centimeter.
Well water from tanks	182
Softened water	4

Reduction=98 per cent.

These results, and especially those obtained on the industrial scale, conclusively prove that Clark's process is a most valuable agent for purifying water biologically, and the value of the process from a chemical point of view is illustrated by the following analyses:

PARTS PER 100,000.

	Total Solids.	Organic Carbon	Organic Nitr'gen	Hardness.
Caterham water-supply before softening	27.68	0.028	0 009	21.2
After softening by Dr. Clark's process	8.80	0.015	0.003	4.4

GAILLET AND HUET'S PROCESS.

	Well at Clyde Wharf, Victoria Dock.	Ditto after Softening.
Total solids	58.76	44.20
Organic carbon	0.111	0.084
Organic nitrogen	0.017	0.016
Ammonia	0.050	0.060
Nitrogen as nitrates and nitrites	0	0
Chlorine	16.7	17.3
Hardness (Temporary	19.8	2.4
Hardness (Permanent	8.0	6.0
Hardness (Total	27.8	8.4
Sulphuric acid	3.96	4.01
Silica	1.44	0.69
Alumina and oxide of iron	0.22	0.14
Lime	12.57	5.96
Magnesia	2.82	0.57
Potash	0.93	1.06
Soda	13.13	15.76
Carbonate of soda	0	2.0
Carbonate of lime	21.32	5.39
Carbonate of magnesia	1.43	1.20
Suspended matter:		
Mineral	0.22	
Organic	0.10	turbid.
Total	0.32	

On comparing the reduction of the organic matter, as indicated by chemical analysis, with the diminution in the number of micro-organisms revealed by the biological examination, it will be seen that the biological efficiency of Dr. Clark's process is markedly superior to its power as a chemical purifier. This is obviously a matter of great importance, as it shows the value of methods of precipitation in removing micro-organisms; it must,

however, be borne in mind that the particular precipitation process referred to above, is carried out with the greatest care and cleanliness, and it is a rule, to which there is no exception, that satisfactory results, as regards the removal of micro-organisms, can only be obtained when the most scrupulous care and continuous attention are given to the matter, and failure will inevitably result when such processes are not under proper supervision.

IV. Purification by Natural Agencies.

It is a matter of common knowledge that of natural waters the purest, as regards organic matter, are those which have undergone prolonged filtration through porous strata. Such waters obtained from deep wells and deep-seated springs often contain the merest trace of organic matter, which is only discoverable and capable of being quantitatively determined by the most refined analytical methods. It has also been shown by Pasteur that many of these waters are entirely destitute of organic life, or are in other words sterile.

Of a number of waters of this kind, the author has only met with isolated samples in which absolutely no organic life was revealed by cultivation with the gelatine mixture, although many have closely approached this ideal state of things. It must, however, be remembered that the collection of natural waters of this kind in a sterile condition is fraught with great difficulty, inasmuch as the places where such waters issue are almost invariably surrounded by conditions which favor the communication of organized matters to the water. Thus the damp, earthy surfaces with which the issuing water comes in contact forms a favorable seat for the development of many growths. It is probably in consequence of such contact at the surface that subterranean waters, like that of the Kent Company, are found to contain their complement, a small one only, it is true, of organic life capable of growth and multiplication in the gelatine-peptone medium. Thus the water collected direct from the Kent Company's well at Deptford contained

	Organisms per cubic centimeter.
June 4th, 1885 (temperature 12°.4 C.)...	6
Oct 29th, " (" 12°.0 C.)...	6
Nov. 25th, " (" 11°.7 C.)...	8

Again, the water from a spring in the Upper Greensand near Reigate contained

	Organisms per cubic centimeter.
June 5th, 1885.....	8
And water from a deep well in the chalk at Sudbury, March 16th, 1886, contained.....	25

It has often been urged as an objection to the bacteriological examination of water, that such an examination fails to distinguish between organisms which are dangerous and those which are harmless. This is, however, not the case, for there are several pathogenic or disease-producing organisms which may be readily discovered; indeed, in the case of cholera in India, this has already been done by Dr. Koch, who found the "Comma Bacillus" in a water-tank which was being used by persons suffering from cholera. The organisms of several other diseases, of which splenic fever "Bacillus anthracis" may be specially mentioned, are also capable of identification. It is only a matter of time and further investigation that other diseases shall become similarly recognisable, inasmuch as every day more precise knowledge of these forms is being acquired. The energy and enthusiasm with which this branch of study is being prosecuted is nowhere more apparent than in the Hygienic Institute of Berlin, which is directed by Dr. Koch under the auspices of the German Government. This institute has as much space and accommodation devoted to the interests of bacteriology alone as, in a government institution in this country, would be accorded to nearly all the sciences put together.

In the application of the gelatine process to the examination of potable water, the author points out that an opinion as to the biological purity of the water should be based not only upon the aggregate number of organisms found, but also upon the number of different varieties which the cultivation reveals. A water containing only one or two varieties is, *cæteris paribus*, to be preferred to one in which there are many varieties, as in the latter case it is evident that the water has been subject to numerous sources of contamination, and that it has not been exposed to influences inimical to the life of a number of different classes of micro-organisms. In his experiments on the artificial purification of water, he

has always found that it is more difficult to remove some classes of organisms than others. The following case illustrates this point in a most striking manner. In the experiments on filtration through vegetable-charcoal it has been already seen that the

	Organisms per cubic centimeter.
Unfiltered water contained.....	2,230
Filtered " "	506

Reduction=77 per cent.

If, however, only those organisms which cause liquefaction of the gelatine be taken into consideration, it is found that

	Organisms (liquid) per cubic centimeter.
Unfiltered water contained.....	785
Filtered " "	1

Reduction=99.87 per cent.

Gelatine Process applied to London Waters.—For more than a year past the author has made periodical examinations by this process of all the waters supplied to the metropolis, and the results obtained since September last have been officially furnished to the Local Government Board.

These examinations are of peculiar interest, when they are studied side by side with the results of similar examinations made of the river waters from which the metropolitan supply is mainly derived. It is, of course, impossible to obtain perfectly representative samples of the water before and after treatment by the companies, but the plan adopted has been to collect samples of the river-water as it passes the companies' intakes on the same day as that on which the samples of the water actually supplied to the consumer are collected. In this manner the samples, taken over a considerable period of time, will be representative of the average quality of the river-water on the one hand, and of the actual supply on the other. A mere glance at the results of these observations, which are embodied in the following table, will distinctly show the striking improvement, as regards the number of micro-organisms, which the river-waters undergo in passing through the companies' works. During the last four months of 1885, the average reduction in the number of micro-organisms effected by the treatment of the companies was as follows:

1885.	Thames.	Lee (East London Co.)
September..	97.8 per cent.	—
October. .	96.5 "	—
November..	98.9 "	98.5 per cent.
December...	98.5 "	88.8 "

These regular periodical examinations have already yielded some exceedingly important results.

Thus for the first time a definite conception has been obtained of the effect of sand-filtration upon these lower forms of life. Hitherto those who were acquainted with the size of these minute microscopic organisms on the one hand, and with the dimensions of the pores in a sand-filter on the other, have believed that little or no barrier could be offered to these organisms by the comparatively spacious pores of the filter, and even the strongest advocate of sand-filtration could not have reasonably anticipated that mere filtration through a few feet of this material could effect the remarkable reduction in the number of micro-organisms to which the above table bears witness.

It is most remarkable, perhaps, that these highly satisfactory results have been obtained without any knowledge on the part of those who construct these filters, as to the conditions necessary for the attainment of such results. In the construction of filter-beds, waterworks engineers have certainly never been guided by an acquaintance with the habits of micro-organisms, and yet by carefully improving their methods, so as to secure the removal of visible suspended matter, they have hardly less successfully, although unconsciously, attracted the invisible particles, and reduced them to an extent which is surprising.

The table, however, also shows that, great as has been the intuitive wisdom of the engineers, there is still much to be learnt in the purification of water from this new point of view. A glance at the table shows that there is a certain uniformity in the position which the various companies occupy as regards freedom from micro-organisms, and on referring to the statistics of the various companies published in Sir Francis Bolton's manual of the "London Water Supply," it is found that there is an unmistakable relationship between this position of each company and certain factors in the mode of working, which might be anticipated from theoretical considerations.

The factors which, in the author's opinion, are more especially calculated to influence the number of micro-organisms present in the distributed water are the following:

1. Storage capacity for unfiltered water.
2. Thickness of fine sand through which filtration is carried on.
3. Rate of filtration.
4. Renewal of filter-beds.

1. *Influence of Storage Capacity for Unfiltered Water.*—The influence which this factor may exercise upon the organized matter in water is manifold. In the first place, through greater storage-capacity, the necessity of drawing the worst water from the river is avoided, a matter which, in the case of a river like the Thames, which is liable to frequent floods, is of great importance. During the period of storage, subsidence takes place, the water becoming poorer in suspended particles of all kinds. Again, in these storage-reservoirs a process of starvation may go on, for the organisms present in the impounded water find themselves imprisoned with a limited amount of sustenance, which they rapidly exhaust, and then perish in large numbers, falling to the bottom. This phenomenon is sufficiently familiar to all who have made the cultivation of micro-organisms a subject of study.

2. *Influence of thickness of Fine Sand.*—That the thickness of the filtering stratum should exercise an important influence on the number of micro-organisms passing through the filter, will be sufficiently obvious to every one. In referring to his laboratory experiments on filtration, the author has already pointed out that comparatively thin strata of various materials are capable of largely, and sometimes of wholly, removing the micro-organisms in the water passing through them, but that this power is gradually lost; it is only reasonable to suppose that a thicker stratum will lose this power less rapidly than a thinner one. In estimating the thickness of the filtering stratum, the fine sand only should be taken into consideration, as it is only this portion of the filter which can have any effect in the removal of micro-organisms.

3. *Influence of Rate of Filtration.*—That the removal of micro-organisms is less perfect when the rate of filtration is increased, and *vice versa*, has been illustrated by the results obtained in the experiments already referred to.

4. *Influence of Renewal of Filter-beds.*—As already pointed out, even the most perfect filtering media sooner or later lose their power of retaining micro-organisms, and hence the importance of frequent renewal is sufficiently apparent.

In considering how the differences in these various factors, which the statistics of the Water Companies exhibit, may be expected to influence the results obtained in the removal of the micro-organisms, attention must be restricted to the five companies drawing water from the Thames, as it is only these which have approximately the same raw material to deal with; for from the above table it is seen that the amount of organic life found in the River Lee at the intake of the East London Company is very different from that in the Thames at Hampton, and the difference in the case of the New River Company is doubtless even still greater, besides the problem being there complicated by the admixture of a very considerable proportion of deep well-water.

The close proximity of the intakes of the five Thames companies, however, furnishes a favorable opportunity for instituting a comparison.

The factors in the mode of working, which have been pointed out as of special importance in exercising an influence upon the result obtained, are given in the table on page 326, the figures being taken from the statistical table given in Sir F. Bolton's "London Water Supply," 1884.

From this the general order of merit can be deduced, by adding these figures together for each company, and arranging them according to their average position, thus:

Companies.	Average Position.	Order of Merit.
Chelsea.....	2.25	2
West Middlesex...	1.5	1
Southwark.....	2.5	3
Grand Junction...	3.75	4
Lambeth.....	4.0	5

From the theroetical considerations here instituted, it would be anticipated, therefore, that dealing with the same raw material, the West Middlesex Water

MORE IMPORTANT FACTORS IN MODE OF TREATMENT PRACTICED BY THAMES WATER COMPANIES.

Name of Company.	Average Daily Supply, in Millions of Gallons.	Available Storage Capacity, in Millions of Gallons.	Average Storage in Days (Calculated.)	Rate of Filtration per Square Foot in Gallons per Hour.	Thickness of Fine Sand.	Renewal of Filter Beds (Calculated). Acreage Cleaned per Month.
					Ft. Ins.	Total Acreage.
Chelsea	9.5	140.0	14.7	1.75	4 6	0.59
West Middlesex	12.8	117.5	9.2	1.5	3	0.90
Southwark	19.9	66.0	3.3	1.5	3 0	0.90
Grand Junction	14.1	64.5	4.6	1.75	2 6	0.81
Lambeth	14.2	128.0	9.0	2.0	3 0	0.50

By means of this table the companies may now be classified with respect to each of the four factors in question, thus:

Company.	Storage Capacity.	Thickness of Fine Sand.	Rate of Filtration.	Renewal of Filter-beds.
Chelsea	1	1	3	4
West Middlesex	2	2	1	1
Southwark	5	3	1	1
Grand Junction	4	5	3	3
Lambeth	3	3	5	5

Company should, on the whole, obtain the best average result, from a biological point of view, and that the results obtained by the other four companies would follow in the order of Chelsea, Southwark, Grand Junction, and Lambeth. On comparing this series with the number of micro-organisms found during the last four months (September to December) of the past year, it will be seen that this series is in precise accordance with the results obtained, thus:

Average Number of Micro-organisms found during the four months, Sept.-Dec., 1885, in 1 cubic centimeter.	
West Middlesex	6
Chelsea	15
Southwark	37
Grand Junction	64
Lambeth	70

The same series is obtained if the results are taken over the whole year; but in that case the figures for the Grand Junction and for the Southwark in March must be omitted, as on these occasions accidental contamination of these supplies had taken place, an exceptionally large number of micro-organisms being found in these months.

This coincidence between theory and practice most conclusively proves that in attempting the removal of micro-organisms from water it is no longer necessary to work in the dark, but that the problem is as tangible as the removal of those larger suspended particles which have for so long past occupied the attention of waterworks-engineers. The only difference between the two, is that the larger suspended particles are visible to the naked eye, whilst these minute living particles require the assistance of science

APPENDIX.—MICRO-ORGANISMS IN 1 CUBIC CENTIMETER OF METROPOLITAN WATERS.

	1885.									
	Jan.	Feb.	Mar.	May.	June.		Sept.	Oct.	Nov.	Dec.
River Thames at Hampton...	—	—	—	—	—	—	1,644	714	1,866	4,650
Chelsea	8	23	10	14	22	81	13	34	33	9
West Middlesex.....	2	16	7	3	—	26	2	2	5	15
Southwark.....	13	26	246	24	—	47	18	24	32	73
Grand Junction.....	382	57	28	3	21	18	43	40	40	134
Lambeth.....	10	5	69	30	—	38	103	26	26	124
RIVER LEE.										
River Lee at Chingford Mill..	—	—	—	—	—	—	—	—	954	2,831
New River.....	7	7	95	3	—	27	3	2	11	18
East London.....	25	39	17	121	—	22	29	53	14	317
DEEP WELLS.										
Kent (well at Deptford).....	—	—	—	—	6	—	—	6	8	5
Kent (Supply).	10	41	9	20	26	—	14	18	—	7

SUMMARY OF FILTRATION EXPERIMENTS.

Name of Material.	Initial Efficiency.	Rate of Filtration.	Efficiency after		Rate of Filtration.	Efficiency after		Rate of Filtration.
	Reductl'n per cent.	Gal pr.sq. ft. pr. hr.			Gal. pr.sq. ft. pr. hr			Gal. pr.sq. ft. pr. hr.
Ferruginous green-sand.....	100	—	13 days. Reduction of	88	0.73	1 month. Reduction of	39.0	1.14
Animal charcoal. ..	100	—	12 days Reduction of	100	0.46	1 month. Increase of	447.0	0.86
Iron sponge.....	100	—	12 days. Reduction of	100	0.40	1 month. Reduction of	99.8	0.45
Brick-dust (pulverized red brick)..	76	—	—		—	5 weeks. Reduction of	93.0	0.48
Coke (A).....	100	—	—		—	5 weeks. Reduction of	98.5	0.50
Coke (B).....	2d day 100	0.89	3 weeks. Reduction of	85	1.32	—		—
Coke (C).....	2d day 100	0.67	3 weeks. Reduction of	90	1.03	—		—
Vegetable charcoal (A)	2d day 100	—	—		—	—		—
Vegetable charcoal (B)	2d day 100	0.22	—		—	1 month. Reduction of	95.0	0.22
Vegetable charcoal (C)	2d day 100	0.26	3 weeks. Reduction of	77	0.59	—		—

to render them apparent. It will also be obvious from the facts brought forward, how necessary it is that these micro-organisms should now receive the careful attention of waterworks engineers, for upon them must ultimately depend the success in practice of the improved processes indicated by scientific research. It is necessary that waterworks-engineers themselves should become experimenters in this field, with the view of ascertaining how their processes may be carried out so as to yield the best results. It is not intended by this that they should be expected to carry out the actual bacteriological operations themselves, for which special training is necessary, but that they should sufficiently acquaint them-

selves with the subject in order to carry out the necessary arrangements for such experiments on the large scale.

It must be pointed out that valuable as are the results obtained when the whole supply of each company is thus periodically submitted to examination, a much deeper insight into the working of the filters is to be obtained by the frequent examination of each individual filter-bed. The examination of the whole supply only gives a summary of the working, and the individual conditions more or less obliterate each other, but by a careful periodical examination of each filter-bed, any defect in a detail of the process of purification would be at once detected and remedied. In fact, it is desirable that the life-history of each individual filter-bed should be carefully studied both for present and future guidance.

The regular biological examination of the water-supply of Berlin has now been carried out for upwards of a year under Dr. Koch, and the importance of this supervision is there duly recognized both by the State authorities and by the water-works-engineers. England has hitherto occupied the first place in the world for the excellence of her sanitary institutions; this place she still maintains; but in future, unless practice goes more hand-in-hand with science, there is every prospect that, as already in industrial prosperity, so in sanitation, she will year by year lose ground in favor of her aspiring neighbors.

The principal conclusions to be drawn from the experiments referred to, are:

I. That the complete removal of micro-organisms from water by filtration is unattainable without frequent renewal of the best filtering materials, and duly restricting the rate of filtration.

II. That a very great reduction in the amount of organized matter in water may be accomplished by filtering materials which have hitherto been generally regarded as almost ineffectual.

III. That organized matter is to a large extent, and sometimes to a most remarkable extent, removable from water by agitation with suitable solids in a fine state of division, but that such methods of purification are unreliable.

IV. That chemical precipitation is attended with a large reduction in the number of micro-organisms present in the water in which the precipitate is made to form and allowed to subside.

V. That if subsidence, either with agitation or after precipitation, be continued too long, the organisms first carried down may again become redistributed throughout the water.

PROPOSED INCREASE OF DUTY IN RUSSIA ON FOREIGN COAL.—Yielding to the clamor of the Russian protectionist press, the Minister of Finance has recommended to the Council of Ministers that the duty on foreign coal imported, *viâ* the Black Sea, should be raised from two copecks per pood to three copecks. This is the second advance that has taken place during the last few years, and is probably only the forerunner of further enhancements. The jump from 3s. a ton to 4s. 6d. is hardly what the Russian press expected, as a demand had been made for a duty of nearly 6s.; but it will give the Donetz coal an opportunity of showing whether it can rise to the occasion and compete with the foreign article or not. Last time the duty was so arranged that the foreign coal, weighted with the new tariff, should be just a trifle dearer than Donetz coal. Directly the duty was imposed, however, the price of foreign coal fell—cheaper freights favoring the downward movement—and ever since English coal has been selling at Odessa 2s. or 3s. cheaper a ton than the native fuel. The duty proposed is not sufficiently heavy to give the latter any advantage over the former, and on this account the press is angry that the minister should not have gone a little further in the path of protection while at it. In the Baltic, the minister proposes no alteration of the duty at all, leaving it at 9d. per ton as at present. This policy is easily understood. The South Russian coalfields are not sufficiently developed to furnish a cheap supply of fuel for the Baltic region, and the various engineering undertakings which the Government has favored with subsidies or bounties, would have to close their establishments if deprived of cheap coal. In all likelihood the tariff in the Baltic will be left as it is for several years to come, until railway communication between the Donetz region and St. Petersburg is more improved, or the coalfields of the Vistula province more developed. We believe that the latter will tell, at no distant date, upon the coal market of North Russia, particularly now that a German syndicate has taken over the Ivangorod-Dombrova Railway, tapping the Polish coalfields. The Vistula coal is very abundant and of better quality than Donetz coal, and already commands a ready sale on the Polish railways and in the factories of Warsaw. Most of the mines are in German hands, and efforts are being made to secure favorable railway rates for sending it to Riga, Revel, and other Baltic ports. When matters are ripe the Russian Government will assuredly impose a heavier duty on foreign coal imported *viâ* the Baltic, probably assimilating the tariff with that prevailing in the Black Sea.

NEW PRACTICAL FORMULAS FOR THE RESISTANCE OF SOLID AND BUILT BEAMS, GIRDERS, ETC., WITH NUMEROUS PROBLEMS AND DESIGNS.

By P. H. PHILBRICK, Professor of Civil Engineering, State University of Iowa.

Written for Van Nostrand's Engineering Magazine.

I.

By practical formulas is meant, those which are both simple and accurate, those which can be easily and safely used.

It is well known that the moment of inertia is a factor in most formulas involving the moment of resistance; and that we usually arrive at the latter through the former. Otherwise we have little interest in the moment of inertia. The moment of resistance, however, does express something fundamentally essential; and the best formulas for the same are therefore very desirable. This will be clear as we proceed.

Accurate formulas for the moment of resistance of all usual sections are well known, but, being more or less complex, and therefore unmanageable by many Bridge Engineers and Architects, other formulas more simple and *seemingly* quite correct, but unfortunately very erroneous, have come into general use.

The main objects of this treatise are:

1°. To deduce and set forth simple and accurate formulas for the resistance of beams, girders, etc.

2°. To point out, to some extent, the errors of the formulas in general use, and the reasons for the existence of these errors.

3°. To apply the new formulas in the examination of existing cases and in designing floor beams, track stringers, etc.

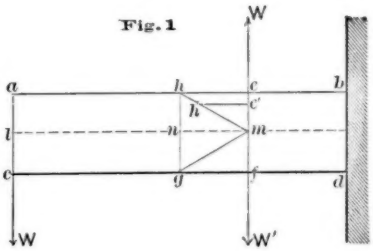
The nature and importance of the moment of resistance will be best understood by first considering the forces that, in ordinary cases at least, produce it. We may then advantageously confine the discussion to the moment of resistance itself.

I. Let *abcd* (Fig. 1) represent a beam fixed at the end *bd* and loaded with a weight W at the free end *ac*. Length of beam $=ab=l$.

It it is evident that the fibers on the lower part of the beam will be compressed, and those on the upper part extended; and that, as a consequence, the beam will bend.

The fibers on some intermediate plane, *em*, will therefore be neither compressed nor extended. This plane is called the neutral plane or axis.

Fig. 1



The main points of the common theory of the resistance of beams to external forces in general are:

1°. The extensions and compressions of the fibers are directly as the forces that produce them.

2°. The forces, and therefore the compressions and extensions also, are directly as their distance from the neutral axis.

3°. The neutral axis passes through the center of gravity of the section.

We are now prepared to explain the nature of the equilibrium between the external and internal forces.

Consider any section, *ef*, perpendicular to the axis of the beam.

Let b=the breadth, d=the depth and x=lin, the distance from the free end to any section considered.

We will first consider the external forces. Take moments about m. The moment of W is Wx, and this can be balanced only by the moments of the strains upon the fibers both above and below m, about the same point m. The force W also produces a shearing or cross strain,

equal to W, upon every vertical section of the beam; and this strain can be met only by an equal stress upon the fibers in the same direction. By applying the equal and opposite forces W and W′ on the section *ef*, the external strains may be made more apparent to some.

Since these forces balance each other, they cannot disturb, or in any way change the existing state of things. These forces, however, with the force W at the end of the beam, constitute the couple WxW, whose moment is W$\times lm$=Wx; and the force W′, which creates the shearing upon the section *ef* and upon all sections of the beam.

We see that the shearing strain in a beam loaded as in Fig. 1, is constant on all sections, but that the moment of strain Wx increases with x, or the distance of the section considered from the load. Hence at the fixed end the moment is a maximum, the fibers there are most strained, and the section at the fixed end is the "dangerous" section.

Fig. 2

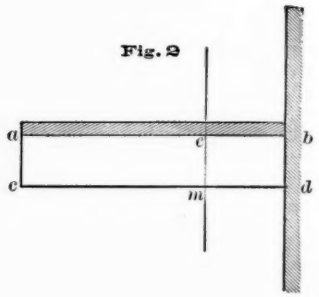


Fig. 3

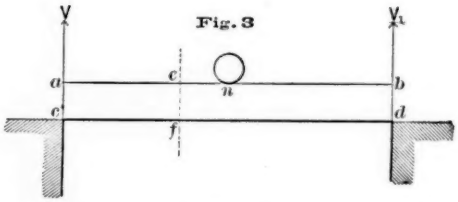
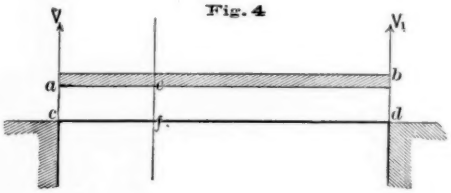


Fig. 4



At the fixed end we have, the maximum moment=M=Wl. (1)

Having found the moment of external forces upon a beam fixed at one end and loaded with a weight W at the free end, we will proceed to find an expression for the moment of internal forces.

Let s=the strain upon a unit of fibers at e take eh=s. Were all the fibers on the cross section *em* of the upper half of the beam equally strained it is plain that the volume of the parallelopiped, whose face is *ehnm* and depth is b (the breadth of the beam), would represent the tension upon the upper half of the beam. Since, however, the strains decrease regularly from the outermost fiber to the center, where the strain is zero, it follows that the strain on the upper half of the beam will be represented by the wedge whose face is *ehm* and breadth is b.

The resistance to tension is therefore equal to $\frac{1}{2}\ em\times eh\times b=\frac{1}{4}\ bds$.

The moment of this resistance is equal to this value multiplied by the distance of the center of gravity of the wedge from the center of the beam, which is equal to $\frac{2}{3}em=\frac{1}{3}d$. Hence the moment of resistance is equal to $\frac{1}{4}bds\times\frac{1}{3}d=\frac{1}{12}bd^2s$.

Since the moment of resistance to compression is the same, the total moment of resistance is therefore M=$\frac{1}{6}bd^2s$. (2)

Again, the moment of resistance of the cross section *em* about its lower edge at m is, as just found, $\frac{1}{12}bd^2s=\frac{1}{3}b(\frac{1}{2}d)^2s$ (3).

This shows that the moment of resistance of a rectangle about one edge is equal to one-third ($\frac{1}{3}$) the breadth multiplied by the square of the depth and by the modulus of strain.

In the case of a beam, fixed at one end and loaded at the free end, we have seen that the moment of strain on the cross section at the fixed end of the beam is Wl; and that the moment of the resisting forces on the fibers is $\frac{1}{6}\ bd^2s$, the notation being as heretofore. These quantities must be equal, and hence

$$Wl=\tfrac{1}{6}bd^2s \qquad (4)$$

In all cases, the moment of external forces called the "bending moment" must be equal to the moment of internal forces, that is to the "moment of resistance."

S of course increases with W, and whether in any given case, s is as great as the material will stand, in which case it is at the point of rupture, depends upon the load W, that the beam has to sustain, and upon the area and form of the cross section of the beam.

For a *given* load W, we solve for s and find,

$$S=\frac{Wl}{\frac{1}{6}bd^2}=\frac{6Wl}{bd^2} \qquad (5)$$

For a given or allowable value of s we solve for W and find

$$W=\frac{\frac{1}{6}bd^2s}{l}=\frac{bd^2s}{6l} \qquad (6)$$

CASE II.

Let the beam be fixed at one end and uniformly loaded.

Let w=load per unit of length.

W=total load. Other notation as before.

Consider a section t *em*.

Load on $ae=wx$. The center of gravity of the load is at a distance from e equal to $\frac{1}{2}x$. Hence the moment of the load about e is equal to

$$M=wx\times\tfrac{1}{2}x=\tfrac{1}{2}wx^2.$$

At the fixed end

$$x=l \text{ and } M_o=wl\times\tfrac{1}{2}l=\tfrac{1}{2}Wl \qquad (7)$$

CASE III.

Let the beam (Fig. 3) be supported at the ends and carry a weight W at the middle point u. Notation as before. One half of the load will be carried to each support. Hence the reactions V and V_1 are each equal to $\frac{1}{2}W$.

The moment of strain on any section ef is $\frac{1}{2}Wx$. The greatest strain on the left hand half of the beam corresponds to the greatest value x can have for that half, and which is equal to $\frac{1}{2}l$. Hence the greatest strain on that half, and therefore on the beam is,

$$M_o=\tfrac{1}{2}W\times\tfrac{1}{2}l=\tfrac{1}{4}Wl \qquad (8)$$

CASE IV.

Let the beam (Fig. 4) be supported at the ends, and uniformly loaded as in Case II. Notation as usual. We evidently have $V=V_1=\frac{1}{2}W$. Hence at any section ef we have the moment of $V=\frac{1}{2}Wx$. The load between V and e is equal to wx, and its lower arm is $\frac{1}{2}x$; hence the moment of that load is $\frac{1}{2}wx^2$.

Since this moment acts in the opposite direction from the moment of V, their difference gives the moment on the section. Hence $M=\frac{1}{2}Wx-\frac{1}{2}wx^2$. Putting $x=\frac{1}{2}l$, this becomes

$$M_o=\tfrac{1}{4}Wl-\tfrac{1}{8}Wl=\tfrac{1}{8}Wl \qquad (9)$$

To prove that equation (9) gives the greatest strain upon the left hand half of the beam, and consequently upon the beam, since the beam is symmetrical about the center, put $x=\frac{1}{2}l-a$ in the value for M and we have:

$$M=\tfrac{1}{2}W(\tfrac{1}{2}l-a)-\tfrac{1}{2}w(\tfrac{1}{2}l-a)^2=\tfrac{1}{4}Wl-\tfrac{1}{2}Wa$$
$$-\tfrac{1}{8}wl^2+\tfrac{1}{2}wla-\tfrac{1}{2}wa^2.$$

But $\frac{1}{2}wla=\frac{1}{2}Wa$ $\therefore$ $M=\frac{1}{4}Wl-\frac{1}{8}wl^2-\frac{1}{2}wa^2$
$=\frac{1}{8}Wl-\frac{1}{2}wa^2$,

which is less than M_o given by (9).

Substituting $\frac{1}{2}l\pm a$ for x will give precisely the same result and show that the strains are symmetrical with reference to the center, which, in the nature of the case, we know to be true, and that the strain is a maximum at the center.

Putting the differential coefficient of $M=\frac{1}{2}Wx-\frac{1}{2}wx^2$ equal to zero, we have,

$$\frac{dM}{dx}=\tfrac{1}{2}W-wx=o \quad \therefore x=\frac{\frac{1}{2}W}{w}=\tfrac{1}{2}l,$$

for the point of maximum strain as already found.

Comparing equations (1), (7), (8) and (9), we see that, for the same total load, in the four cases considered, the moments of strain upon the sections of greatest strain, and consequently the moment of stress upon the fibers, as well as the stress upon the fibers, are as the numbers 8, 4 2 and 1. Hence the beams are capable of carrying loads, disposed as shown, in the ratio of 1, 2, 4 and 8.

For example, a beam supported at the ends and uniformly loaded will carry eight times as great a load as the same beam will carry when fixed at one end and loaded at the free end.

In the first case, the shearing stress, which we will represent by S, is constant and equal to $S_1=W$ (10).

In the second case, the shearing stress

at any section *ef* is evidently equal to the load between the free end and that section, and is $S=wx$. This is a maximum at the fixed end and equal to

$$S_1=wl=W \qquad (11)$$

In the third case, since $V=\frac{1}{2}W$ and there is no load between V and the load at the middle, the shearing stress at all points of the beam is evidently equal to

$$S_1=\tfrac{1}{2}W \qquad (12)$$

In the fourth case the reaction $V=\frac{1}{2}W$ and as the load between the free end and the section *ef* is equal to wx, the shearing stress on that section is equal to $S=\frac{1}{2}W-wx$.

At the end this is a maximum and

$$S_1=\tfrac{1}{2}W \qquad (13)$$

At the middle $S=\frac{1}{2}W-w\frac{1}{2}l=o$.

Example 1.—Suppose the safe stress per square inch to be, $s=1200$ pounds, $l=16$ feet, $b=3$ inches, and $d=12$ inches. What weight, uniformly distributed, will the beam, supported at its ends, carry?

From equations (2) and (9) we have:

$$\tfrac{1}{8}Wl=\tfrac{1}{6}bd^2s \text{ or } \frac{W=4bd^2s}{3l}$$

$$=\frac{4\times3\times12^2\times1200}{3\times16\times12}=3600 \text{ pounds.}$$

Example 2. — There are 9 joists $3''\times12''\times17'$ equally spaced, carrying 80 pounds per square foot on the floor of a bridge, which is 16 feet wide. What is the greatest strain per $\square''$ of fibers?

Each of the two outer joists carries but one-half as much as each of the others. Hence each of the middle joists carries $\frac{1}{8}$ of the total load or

$$\frac{80\times16\times17}{8}=2720$$

Now $2720=\dfrac{4bd^2s}{3l}$ and $s=963$ pounds.

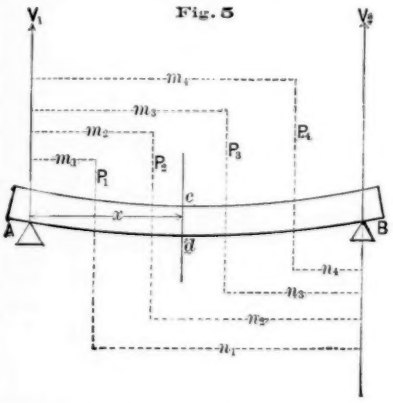
Other Cases of Loading.

Case V.—A beam resting upon two supports and loaded at any number of points. If a beam is loaded in any manner it is only necessary to find the moments of all the forces in reference to the center of the section considered, and place the algebraic sum equal to the moment of resistance of the section. In Fig. (5), let the weights P_1, P_2, P_3, etc. rest upon the beam at distances respectively equal to m_1, m_2, m_3, etc. from one support; and n_1, n_2, n_3, etc. from the other. Let l=the distance between the supports, and V_1 and V_2 the reactions at the supports. Consider any section, *cd*, distant x from the support A. The sum of the moments of the forces on the section *cd* is

$$V_1\times-P_1(x-m_1)-P_2(x-m_2)-\text{etc.}$$

to include all the P's between A and *cd*.

Fig. 5



For rectangular beams we have therefore

$$V_1x-P_1(x-m_1)-P_2(x-m_2)-\text{etc.}=\tfrac{1}{6}bd^2s. \qquad (14)$$

To find V_1 take moments about B and find,

$$V_1l=P_1n_1+P_2n_2+P_3n_3+\text{etc.}=\Sigma Pn$$

$$\therefore V_1=\frac{\Sigma Pn}{l}\text{; similarly } V_2=\frac{\Sigma Pm}{l}.$$

$$\text{Also } V_1+V_2=P_1+P_2+P_3+\text{etc.}=\Sigma P.$$

In case of a single weight P_1, Fig. (6), the preceding formulas give,

$$V_1=\frac{P_1n_1}{l},\ V_2=\frac{P_1m_1}{l} \text{ and}$$

$$V_1+V_2=\frac{P_1}{l}(n_1+m_1)=P_1.$$

From these we have for any section distant x from A, the moment equal to

$$M=V_1x=\frac{P_1}{l}n_1\times. \qquad (15)$$

Similarly for a point distant x from B,

$$M = V_2 x = \frac{P_1}{l} m_1 x. \qquad (16)$$

Since $\frac{P_1}{l}$ is constant we see that the strain on *any* section varies as the product of the end segments, into which the beam is divided by the weight and the section.

Fig. 6

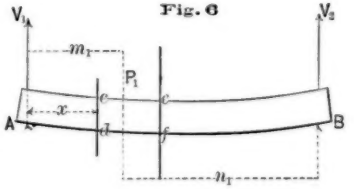
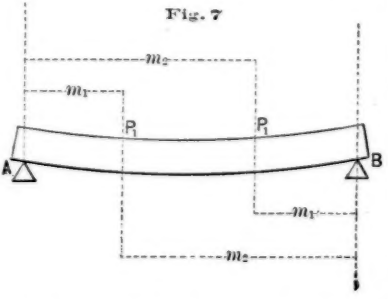


Fig. 7



Again, making x the same in (15) and (16), we see that sections on opposite sides of the weight and equally distant from the supports, are strained in the ratio of the segments into which the weight divides the beam.

In case of two equal weights P_1 and P_1, symmetrically placed upon the beam as shown.

We have $V_1 = \frac{P_1 m_2 + P_1 m_1}{l} = P_1$.

Similarly $V_2 = P_1$.

For any section between A and P_1 the moment is $M' = V_1 x = P_1 x$, which is less than $P_1 m_1$.

For any section between the weights, the moment $= V_1 x - P_1(x - m_1)$

$$= P_1 x - P_1(x - m_1) = P_1 m_1 \qquad (17)$$

The strain therefore increases from zero at either support to the adjacent weight, and remains constant between the weights.

If, in Fig. 8, pc or $p'c'$ represents the moment of strain under the weights, any ordinate as ef will represent the strain at the point e.

For a uniformly distributed load of $2P_1$, eq. (9) gives,

$$M'' = \tfrac{1}{8} l (2P_1) = \tfrac{1}{4} P_1 l \qquad (18)$$

Comparing eqs. (17) and (18), we see that the greatest strain in the case of a uniformly distributed load is to that of the same load when placed as in Fig. 7, as $\frac{1}{4}l$ is to m_1.

Fig. 8

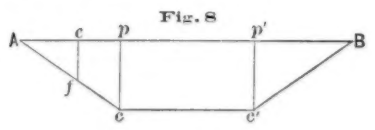
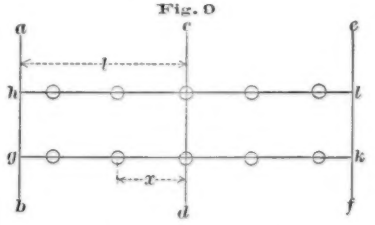


Fig. 9



Since tables are usually arranged to give the strains for a uniformly distributed load, on floor beams, track stringers, etc., it becomes important to notice and provide for increased strains due to concentrated loads as above.

Example.—A floor beam of a railway bridge is 14 feet long between supports and carries a single track, the gauge being 4 feet and 8 inches. The beam is designed to carry a distributed load just equal in amount to the eccentric load upon it. What is the capacity of the beam?

We have $m_1 = \frac{14 - 4\frac{2}{3}}{2} = 4\frac{2}{3}$. The load on the beam is, $\frac{m_1}{\frac{1}{4}l} = \frac{4m_1}{l} = \frac{18\frac{2}{3}}{14} = \frac{4}{3}$ times the load it is able to carry. Hence it is able to carry $1 \div \frac{4}{3} = \frac{3}{4}$ of the given load; or it has a capacity of 75%.

It is worthy of notice that the greatest load that can come upon a floor beam, for example, for a given weight of engine per foot, depends upon the relative lengths of panel and wheel space, that is, the distance between consecutive pairs of wheels.

We will show that, in general, a load greater than the weight of the engine for a panel length, can come upon a floor beam; and we will deduce a general expression for the load and the excess of load over a panel load.

Let l = a panel length.

x = wheel space.

w = weight of engine per foot.

$\therefore wx$ = weight on a pair of wheels.

and wl = weight of engine per panel length.

Let $l \geqq nx$ and $l < (n+1)x$, n being an integer.

In Fig. 9, let *ab*, *cd*, *ef*, etc., represent the floor beams, *gk* and *hl* the track stringers, and the circles the position of the wheels. Consider the load on *cd*. Let a pair of wheels rest on *cd*. To find the load on *cd* we have wx resting directly upon *cd*, while $\frac{l-x}{l}wx$ comes upon *cd* from each of the adjacent pairs of wheels, distant x from *cd*; or $2wx\frac{l-x}{l}$ from both pair. Similarly $2wx\frac{l-2x}{l}$ is supported by *cd* from the next two pairs of wheels, distant $2x$ from *cd*, etc., etc.

Hence the total load on *cd* is,

$$L = wx + 2wx\frac{l-x}{l} + 2wx\frac{l-2x}{l} + 2wx\frac{l-3x}{l} + \text{etc.} \ldots\ldots 2wx\frac{l-nx}{l}$$

or $L = wx + 2wx(1+1+1+1+\text{etc. to } n \text{ terms}) - \frac{2W}{l}(^2x2 \times {}^2x3x^2 + \text{etc. to } nx^2)$

$$= wx(2n+1) - \frac{w}{l}n(n+1)x^2 \quad (19)$$

Putting the differential coefficient of this equal to zero we find

$$(2n+1) - \frac{2n(n+1)}{l}x = 0$$

$$\text{or } x = \frac{(2n+1)l}{2n(n+1)} \quad (20)$$

Substituting this value of x in (19) and reducing, we find the maximum load on

$$cd = L_0 = Wl\frac{(2n+1)^2}{4n(n+1)} = Wl\frac{4n(n+1)+1}{4n(n+1)}$$

$$= Wl + \frac{Wl}{4n(n+1)} \quad (21)$$

L_0 is therefore greater than Wl; but the excess over Wl decreases as n increases. For $n=0$ we have $L_0 = \frac{Wl}{0} = \infty$.

But $n=0$ gives from above $x = \frac{l}{0} = \infty$ and

$\therefore wx = \frac{wl}{0} = \infty$ as it ought.

From (20), $l - nx = \frac{l}{2(n+1)}$ (22)

This shows the space between the nth pair of wheels from *cd* and the adjacent floor beam.

For $n=1$ (20) and (22) give, $x = \frac{2}{3}l$, and $l - x = \frac{1}{3}l$.

For $n=2$ (20) and (22) give, $x = \frac{5}{12}l$, and $l - 2x = \frac{1}{6}l$.

For $n=3$ (20) and (22) give, $x = \frac{7}{24}l$, and $l - 3x = \frac{1}{8}l$.

For $n=1$ we have $L_0 = \frac{8}{9}wl$.

For $n=2$ we have $L_0 = \frac{24}{25}wl$.

For $n=3$ we have $L_0 = \frac{48}{49}wl$.

For $n=4$ we have $L_0 = \frac{81}{80}wl$, etc.

These results show that the excess of load is slight, except for short panels and wide wheel spaces, in which case it may amount to $\frac{1}{9}$ or $12\frac{1}{2}\%$ of a panel load.

Example.—In a railway bridge, the length of panels is $l=10$ feet; the distance between pairs of wheels is $x=7\frac{1}{2}$ feet. Load, 4,000 pounds per foot. Find the greatest load supported by a floor beam and the excess over a panel load.

The load supported is

$\frac{8}{9}wl = \frac{8}{9} \times 4{,}000 \times 10 = 45{,}000$ pounds.

A panel load is

$wl = 4{,}000 \times 10 = 40{,}000$ pounds.

The excess is therefore

$\frac{1}{9}wl = 500 \times 10 = 5{,}000$ pounds.

To prove that the maximum strain occurs when a pair of wheels rests upon the beam as in Fig. 9, let us suppose the engine to move to the right (say) a distance $= \frac{l}{2(n+1)}$ [see Eq. (22)], so that it will occupy the position shown in Fig. 10.

It is evident that only a part of the weight, wx, resting upon *cd* in Fig. 9 rests upon *cd* in Fig. 10, and that so far as the other weights are concerned, the increased load upon *cd* from the weights at the left of *cd* is exactly balanced by the

decreased load upon cd from the weights at the right of cd. The load upon cd is less than in Fig. 9, by

$$\frac{\frac{l}{2(n+1)}}{l}\ wx=\frac{(2n+1)l}{2n(n+1)2(n+1)}n$$

$$w=\frac{2n+1}{4n(n+1)^2}w \quad (23)$$

2°. Again let us suppose the engine to move from the position shown in Fig. 10 to that shown in Fig. 11. From what has been said, it is evident that no change in the load upon cd has taken place.

3°. Finally we will suppose the engine to move from the position of Fig. 11 to that of Fig. 12. It is evident that this movement is the reverse of the first, and that the load will increase therefore during this change, precisely as it decreased during the first.

Fig. 10

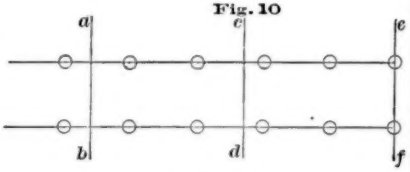
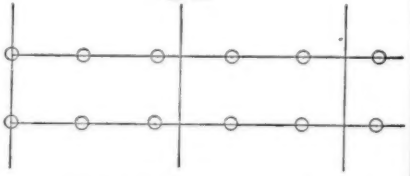


Fig. 11



In Fig. 13, let bb' represent a wheel space, then the ordinate ab represents the maximum load on the beam corresponding to Fig. 9, while cd and $c'd'$ represent the minimum loads corresponding to Figs. 10 and 11, and $a'b'$ the maximum corresponding to Fig. 12, which is the same as Fig. 9.

We see that while the engine advances a wheel space, the load upon a beam decreases for a part of that distance, remains constant during the second part, and increases again during the third part. The smallest loads upon the floor beam (cd), corresponding to the positions shown in Figs. 10 and 11, or any position between these two, are not minimum loads, but simply the loads corresponding to certain positions of the engine, when the wheels are spaced to produce a maximum load.

To find the wheel space for a minimum load upon a floor beam, when a pair of wheels is over a beam. Eq. (20) gives the value of x for a maximum load.

Put $x=\frac{2n+1}{2n(n+1)}l+a$ in (19) and we find

$$L'=\frac{(2n+1)^2}{2n(n+1)}wl+wa)2n+1)$$
$$-\frac{w}{l}n(n+1)\left(\frac{2n+1}{2n(n+1)}l+a\right)^2$$
$$=\frac{(2n+1)^2}{4n(n+1)}wl-\frac{w}{l}n(n+1(a^2 \quad (24)$$

Eqs (21) and (24) give,

$$L_0-L'=\frac{w}{l}n(n+1)a^2 \quad (25)$$

Fig. 12

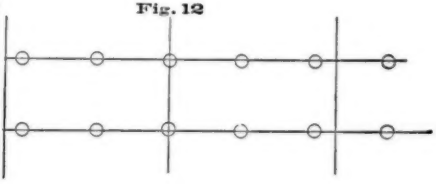
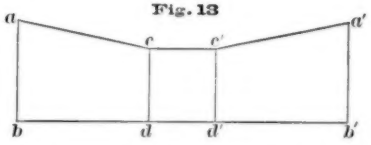


Fig. 13



This shows that the greater a is, the less the load upon the beam.

Now $l=nx+(l-nx)=n\left(x+\frac{l-nx}{n}\right)$

This shows that if the wheel space is increased by the nth part of the excess of a panel length over a wheel space, n times the increased wheel space will equal a panel length.

Hence a cannot exceed $\frac{l-nx}{n}$

But Eq. (22) gives,

$$\frac{l-nx}{n}=\frac{l}{2n(n+1)}=a \quad (26)$$

Putting this value of a in (24) we get,

$$L'=\frac{(2n+1)^2}{4n(n+1)}wl-\frac{w}{l}n(n+1)\frac{l^2}{4n^2(n+1)^2}$$
$$=\frac{(2n+1)^2}{4n(n+1)}wl-\frac{1}{4n(n+1)}wl=wl \quad (27)$$

The minimum load upon the beam corresponds to wheel spaces equal to a panel length, or to an aliquot part of the same; the minimum load being equal to a panel load.

It is not so necessary to consider the increased strains upon floor beams, etc., in case of a double track, though we may just as easily do so; for, in the first place, the loads upon the beams are much more nearly distributed than in the case of a single track; and, furthermore, the loads on the two tracks would rarely occupy the same position with reference to the floor beam.

A Partial Uniform Load.

Let a beam be uniformly loaded over *any* portion of its length.

Fig. 14

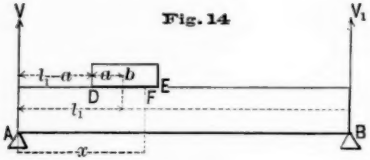
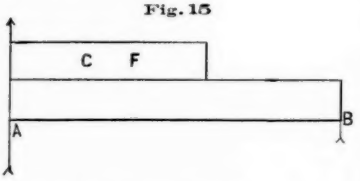


Fig. 15



Let l=AB, the length of the beam,
$2a$=DE, the length of the load,
x=AF, the distance to any section,
C=the center of the load,
l_1=AC, w=load on a unit of length,
V=the reaction of support A.

Then $AD=l_1-a$ and $DF=x-(l_1-a)=x+a-l_1$.

The load on $DF=w(x+a-l_1)$.

The load on $DE=2wa$.

By the principle of moments,

$$Vl=2wa(l-l_1) \quad \therefore V=2wa\left(1-\frac{l_1}{l}\right)$$

The moment of stress at F is,

$$M=Vx-w(x+a-l_1)\tfrac{1}{2}(x+a-l_1=Vx-\tfrac{1}{2}w(x+a-l_1)^2,$$

or $$M=2aw\left(1-\frac{l_1}{l}\right)x-\tfrac{1}{2}w(x+a-l_1)^2 \quad (28)$$

That value of x which makes (28) a maximum gives the position of the dangerous section.

Differentiate, place equal to zero, and solve for x and find,

$$x=a\left(1-\frac{2l_1}{l}\right)+l_1=l_1\left(1-\frac{2a}{l}\right)+a$$

$$=a+l_1-\frac{2al_1}{l} \quad (29)$$

If $l_1=\frac{1}{2}l$, $\quad x=l_1$.
If $l_1<\frac{1}{2}l$, $\quad x>l_1$.
If $l_1>\frac{1}{2}l$, $\quad x<l_1$.

These results show that the maximum strain is at the center of the loading only when the center of the loading is over the center of the beam, and that in all other cases it is nearer the center of the beam than the center of the loading is.

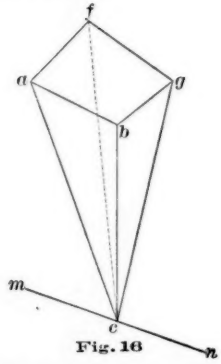


Fig. 16

To find the relative positions of the centers of loading and dangerous section, put $l_1=\frac{1}{2}l\pm d$; then

$$x=a\left(1-\frac{l\pm 2d}{l}\right)+\tfrac{1}{2}l\pm d=\pm d\frac{l-2a}{l}\pm\tfrac{1}{2}l.$$

Now $x-\frac{1}{2}l=\pm d\dfrac{l-2a}{l}$ and $l_1-\frac{1}{2}l=\pm d$.

Hence $$\frac{x-\frac{1}{2}l}{l_1-\frac{1}{2}l}=\frac{l-2a}{l} \quad (30)$$

which shows the ratio of the distances of the dangerous section and the center of loading from the center of the beam.

Differentiating (29) with respect to l_1 and also with respect to a, we find,

$$\frac{dx}{dl_1}=1-\frac{2a}{l} \quad (31)$$

which is positive; and

$$\frac{dx}{da}=1-\frac{2l_1}{l} \qquad (32)$$

which is positive for $l_1<\frac{1}{2}l$ and negative for $l_1>\frac{1}{2}l$.

Eq. (31) shows that x increases and decreases with l_1.

Eq. (32) shows that when $l_1<\frac{1}{2}l$, that is, when the center of loading is between the center of the beam and the origin, x increases and decreases with a; but when $l_1<\frac{1}{2}l$, that is, when the center of loading is on the opposite side of the center of the beam from the origin, x increases as a decreases and vice versa.

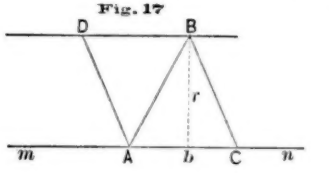
The maximum strain for given values of a and l_1 is found by substituting the value of x from (29) in (28). We have

$$x=a+l_1-\frac{2al_1}{l} \quad \therefore x+a-l_1=2a\left(1-\frac{l_1}{l}\right)$$

$$\text{Hence } M_0=2aw\left(1-\frac{l_1}{l}\right)\left(a+l_1-\frac{2al_1}{l}\right)$$

$$-2a^2w\left(1-\frac{l_1}{l}\right)^2$$

Fig. 17



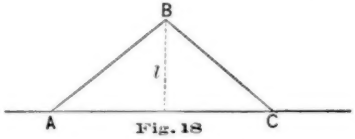


Fig. 18

$$=2aw\left(1-\frac{l_1}{l}\right)\left\{a+l_1-\frac{2al_1}{l}-a\left(1-\frac{l_1}{l}\right)\right\}$$

$$=2aw\left(1=\frac{l_1}{l}\right)\left(l_1-\frac{al_1}{l}\right)$$

$$=2awl_1\left(1-\frac{l_1}{l}\right)\left(1-\frac{a}{l}\right) \qquad (33)$$

The value of a which will make (33) a maximum is found by differentiating the equation with reference to a. We thus find $1-\frac{2a}{l}=0$ or $2a=l$.

Hence the larger the load the greater the strain.

When $2a=l$, $l_1=\frac{1}{2}l$ and $M=.\frac{1}{2}wl^2\frac{1}{2}\cdot\frac{1}{2}$ $=\frac{1}{8}wl^2=\frac{1}{8}Wl$, agreeing with Eq (9) as it ought.

Let $a=\frac{1}{4}l$ and $l_1=\frac{1}{4}l$

Then the strain at F is by (33),

$$M_0=\tfrac{1}{2}wl\cdot\tfrac{1}{4}l_1\tfrac{3}{4}\cdot\tfrac{3}{4}=\tfrac{9}{128}wl^2.$$

To find the strain at the center, we have the load $=\frac{1}{2}wl$; and $V=\frac{3}{4}\cdot\frac{1}{2}wl=\frac{3}{8}wl$.

Taking moments about the center of the beam we have $M'=\frac{3}{8}wl\times\frac{1}{2}l-\frac{1}{2}wl\times\frac{1}{4}l$

$$=\frac{8}{128}wl^2$$

This shows that the strain at the dangerous section for this loading exceeds that at the center by $\frac{1}{8}$, or $12\frac{1}{2}\%$. This excess is the same as the maximum excess coming upon a floor beam from an undistributed load.

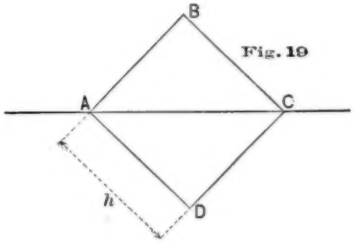


Fig. 19

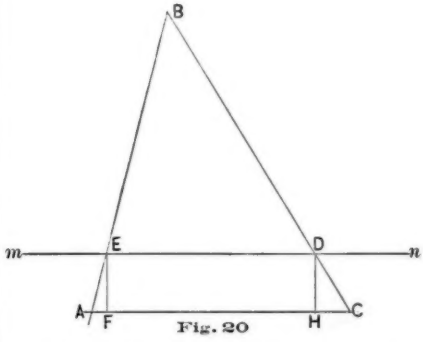


Fig. 20

We will now derive a general formula for the moment of resistance, after which we will deduce the moment of resistance of triangular and other cross sections.

Let s=strain on a unit of fibers, of any cross section, most remote from the neutral axis.

d=distance from the neutral axis to the most remote fiber.

y=distance to any fiber.

δ=an elementary area.

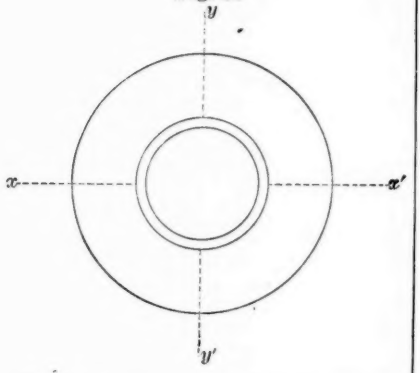
Then $\frac{s}{d}$=strain on a unit of fibers at a distance unity.

$\frac{s}{d}y$=strain on a unit of fibers at a distance y.

$\frac{s}{d}y\delta$=strain on an element of fibers at a distance y.

$\left(\frac{s}{d}y\delta\right)y$=moment of strain on an element of fibers at a distance y.

Fig. 21



This expression, taken for all values of y within the section, will give the moment of strain of the given section. Let M represent this moment. Then

$$M=\Sigma\left(\frac{S}{d}y\delta\right)y=\Sigma\frac{s}{d}y^2\delta=\frac{s}{d}\Sigma y^2\delta \qquad (34)$$

In (34) the factor $\Sigma y^2\delta$ is called the moment of inertia of the cross section and is represented by I. It is obtained by multiplying each elementary area by the square of its distance from the neutral axis and taking the sum of the products. Representing $\Sigma y^2\delta$ by I, we have,

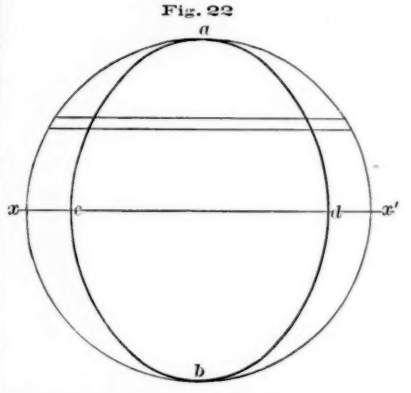
$$M=\frac{S}{d}I \qquad (35)$$

We must not, however, suppose that the moment of resistance involves the product of the strains on the different parts of the cross section into the *squares* of their distances from the neutral axis. The moment of resistance is obtained by multiplying each elementary strain $\left(\frac{s}{d}y\delta\right)$ by its distance from the axis (y). The y^2 in eq. (34) comes from the factor y in the factor of *strain* and the y which expresses the *distance* from the axis.

When S=1, we have $M_1=\frac{I}{d}$ (36)

The quantity $\frac{I}{d}$, that is, the moment of inertia of the surface, divided by the distance of the furthermost fiber from the neutral axis, might with entire propriety be called the unit moment of resistance; for it does represent the moment of resistance of the section corresponding to

Fig. 22



a unit of strain upon a unit of area of fibers most remote from the neutral axis. Since, however, s varies with the nature and quality of the material, while $\frac{I}{d}$ depends only upon the area and form of section, the quantity represented by $\frac{I}{d}$ can be conveniently tabulated while that represented by $s\frac{I}{d}$ cannot so well be. The quantity $\frac{I}{d}$ is, therefore, frequently called the moment of resistance, though $s\frac{I}{d}$ is the real moment of resistance.

The strain upon a unit of fibers most remote from the neutral axis and represented by s, is called the "modulus of strain," or "maximum fiber strain." We may frequently refer to either $\frac{I}{d}$ or $s\frac{I}{d}$ as the moment of resistance or simply resistance, since this will lead to no confusion.

To find the moment of resistance of the triangle abc about an axis mn passing through the vertex c and parallel to ab.

Let $ab=b$ and bc=the altitude of the triangle$=d$.

Draw af and bg, each equal to unity, perpendicular to the plane abc.

It is plain that the total strain upon the triangle is represented by the volume of the pyramid $abfg-c$, which is equal to $ab\times bg\times\frac{1}{3}bc=\frac{1}{6}bd$; and that the moment of resistance is represented by the static moment of the pyramid. The center of gravity of the pyramid is at a distance from mn equal to $\frac{3}{4}d$. Hence the moment of resistance is equal to

$$M=\tfrac{1}{6}bd\times\tfrac{3}{4}d=\tfrac{1}{8}bd^2 \qquad (37)$$

Fig. 23

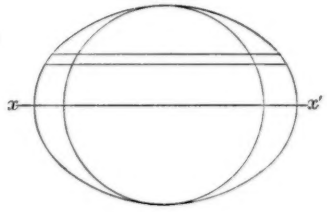
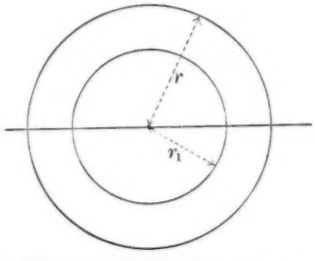


Fig. 24



To find the moment of resistance of a triangle ABC (Fig. 17) about an axis coinciding with the base; we observe that the moment of resistance of this triangle is equal to that of the parallelogram ABCD less that of the triangle ABD. Hence, from eqs. (3) and (37)

$$M_1=\tfrac{1}{6}bd^2-\tfrac{1}{8}bd^2=\tfrac{1}{12}bd^2 \qquad (38)$$

To find the resistance of a triangle having angles at 45° at A and C, and therefore 90° at B.

We have $d=\frac{1}{2}b$ or $d^2=\frac{1}{4}b^2$, and hence

$$M_1=\tfrac{1}{12}bd^2=\tfrac{1}{48}b^3.$$

If BC$=h$, $b^2=2h^2$ and $b^3=2.828\,h^3$, and, therefore,

$M_1=\frac{1}{48}.2.828\,h^3=.059\,h^3=.06h^3$, very nearly. (39)

To find the resistance of a square, whose side is h, about a diagonal from (39), we have,

$$M_1=.118\,h^3=.12\,h^3, \text{ nearly.} \qquad (40)$$

To find the moment of resistance of a triangle about an axis through the center of gravity. Drop the perpendiculars EF and DH upon the base. Observe that DE$=\frac{2}{3}b$, AF$+$CH$=\frac{1}{3}b$; the altitude of BED$=\frac{2}{3}d$ and EF$=\frac{1}{3}d$. Also that the strain along the line AC is only half as much as at the point B. Hence the moment of resistance of

Fig. 25

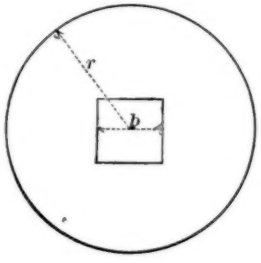
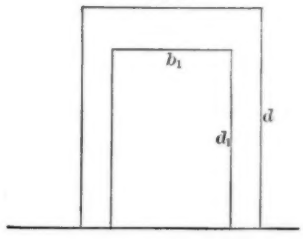


Fig. 26



$$\text{BED}=\tfrac{1}{12}(\tfrac{2}{3}b)(\tfrac{2}{3}d)^2\frac{16}{24\times27}bd^2$$

the moment of resistance of

$$\text{EAF}\times\text{DHC}=\tfrac{1}{2}\text{ of }\tfrac{1}{4}(\tfrac{1}{3}b)(\tfrac{1}{3}d)^2=\frac{3}{24\times27}bd^2$$

and the moment of resistance of

$$\text{EDFH}=\tfrac{1}{2}\text{ of }(\tfrac{2}{3}b)(\tfrac{1}{3}d)^2=\frac{8}{24\times27}bd^2$$

Hence the moment of resistance of

$$\text{ABC}=M_1=\tfrac{1}{24}bd^2 \ldots \qquad (41)$$

Since the equation $M_1=\dfrac{I}{d}$ or $dM_1=I$

is perfectly general, the moment of inertia is equal to the moment of resistance multiplied by the distance from the axis to the outermost fiber; or the moment of resistance is equal to the moment of inertia divided by the same quantity.

To find the polar and plane moments of inertia of a circle.

The polar moment is the moment about an axis through the center perpendicular to its plane.

Fig. 27

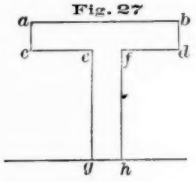
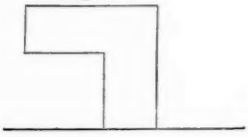


Fig. 28



Let r=radius, y and $y+dy$ the radii of two smaller circles concentric with the other. The area of the annulus is, $\delta=2\pi y dy$, and the square of its distance from the center being y^2, we have the polar moment of inertia of the circle is,

$$I_p=2\pi\int_0^r y^3dy=\tfrac{1}{2}\pi\delta^4 \qquad (42)$$

Now, considering *any* elementary area, it is plain that its polar moment is equal to the sum of its moments about XX′ and YY′.

The polar moment of the *entire* circle is, therefore, equal to the sum of its moments about XX′ and YY′.

But these latter are evidently equal, and hence either is equal to half the polar moment.

Hence $I=\tfrac{1}{4}\pi r^4 \qquad (43)$

The moments of resistance are found, of course, by dividing these expressions by r.

Hence $M_p=\tfrac{1}{2}\pi r^3 \qquad (44)$

and $M_1=\tfrac{1}{4}\pi r^3 \qquad (45)$

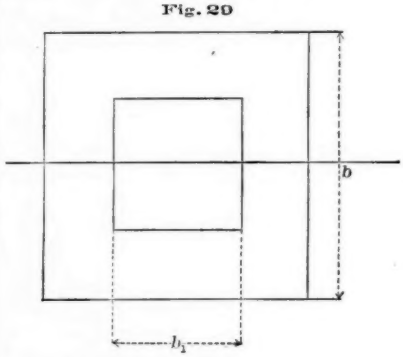
To find the polar moment of resistance directly, we have $\delta=2\pi y dy$ as above. The strain on a unit of area of the outermost fibers of the circle being unity, the strain on a unit of fibers at the distance y, is Y_r. Hence the strain on the annulus is, $2\pi y dy\,\frac{y}{r}\,y=\frac{2\pi}{r}\,y^3dy$; and the moment of that strain is $\frac{2\pi}{r}y^3dy$. Hence

$$M_p=\frac{2\pi}{r}\int_0^r y^3dy=\frac{2\pi}{r}\cdot\frac{r^4}{4}=\tfrac{1}{2}\pi r^3$$

and $M_1=\tfrac{1}{4}\pi r^3$.

To find the moment of resistance of an ellipse about its shorter axis, cd.

Fig. 29



Let $ab=2a$ and $cd=2b$.

Circumscribe a circle about the ellipse. The resistance of the circle is, $\frac{1}{4}\pi r^3=\frac{1}{4}\pi a^3$. But considering *any* elemenary strip parallel to XX′, the length of that strip, included within the ellipse, is to the length included within the circle as b is to a. Hence the resistance of the ellipse is

$$M_1=\tfrac{1}{4}\pi a^3\frac{b}{a}=\tfrac{1}{4}\pi a^2b \qquad (46)$$

For an ellipse about its longer axis inscribe a circle. The notation being as before we have for the circle

$$M_1=\tfrac{1}{4}\pi b^3,$$

and, therefore, for the ellipse,

$$M_1=\tfrac{1}{4}\pi b^3\frac{a}{b}=\tfrac{1}{4}\pi b^2a \qquad (47)$$

A hollow circle (Fig. 24) or annulus. To find the moment of resistance of a section equal to the hollow, we observe that the resistance on the outer limit of the hollow is not unity, but only $\frac{r_1}{r}$. Hence the moment of resistance by (45) is

$$\tfrac{1}{4}\pi r_1^3 \times \frac{r_1}{r} = \frac{\tfrac{1}{4}\pi r_1^4}{r} \qquad (48)$$

That is, the moment of resistance of the hollow is equal to its moment of inertia divided by the distance of the axis from the farthest fiber of the whole section. Hence by (45) and (48) the moment of resistance of the whole section is

$$M_1 = \tfrac{1}{4}\pi r^3 - \frac{\tfrac{1}{4}\pi r_1^4}{r} = \frac{\tfrac{1}{4}\pi r^4 - \tfrac{1}{4}\pi r_1^4}{r} \qquad (49)$$

Hence the moment of resistance of a hollow section is equal to the difference of the moments of resistance of the whole section and that of the hollow; or it is equal to the difference of the moments of inertia of the same sections divided by the distance from the axis to the farthest fiber.

The moment of resistance of the section shown in Fig. 25, for example, is,

$$M_1 = \tfrac{1}{4}\pi r^3 - \frac{\tfrac{1}{12}b^4}{r} = \frac{\tfrac{1}{4}\pi r^4 - \tfrac{1}{12}b^4}{r} \qquad (50)$$

Moment of resistance of a hollow rectangle.

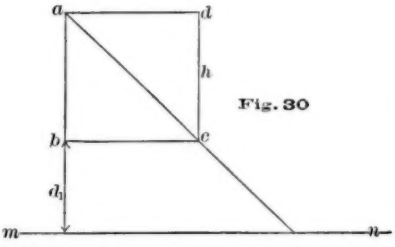


Fig. 30

Eq. (3) gives the moment of resistance of the whole section $= M' = \tfrac{1}{6}bd^2$.

The strain at b_1 is equal to $\frac{d_1}{d}$, therefore for the hollow

$$m'' = \tfrac{1}{6}\frac{d_1}{d}b_1 d_1^2 = \tfrac{1}{6}\frac{b_1 d_1^3}{d}.$$

Hence for the real section

$$m = m' - m'' = \tfrac{1}{6}\frac{bd^3 - b_1 d_1^3}{d} \qquad (51)$$

Formula (51) evidently applies to the "T" section as shown in Fig. 27 or to the "angle" as shown in Fig. 28.

If $d = \frac{1}{2}b$ and $d_1 = \frac{1}{2}b_1$, (51) becomes

$$M_1 = \tfrac{1}{12}\frac{b^4 - b_1^4}{b}, \qquad (52)$$

Hence for a hollow *square* Fig. 29,

$$M_1 = \tfrac{1}{6}\frac{b^4 - b_1^4}{b}. \qquad (53)$$

If $b_1 = b$, the web vanishes and equation (51) gives for the flange alone,

$$M_1 = \tfrac{1}{6}\frac{b(d^3 - d_1^3)}{d} = b(d - d_1)\frac{d^2 + d_1 d + d_1^2}{3d}$$

$$= b(d - d_1)\frac{3dd_1 + (d - d_1)^2}{3d}$$

$$= b(d - d_1)(d_1 + \frac{(d - d_1)^2}{3d}. \qquad (54)$$

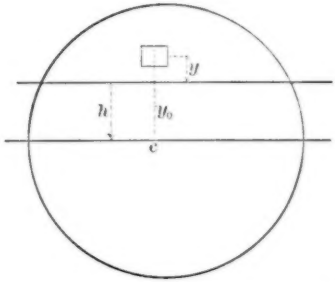
Let $d - d_1 = h$ and $b(d - d_1) = a$ = area of the flange.

Then $M_1 = a\left(d - h + \tfrac{1}{3}\frac{h^2}{d}\right) = a\left(d_1 + \tfrac{1}{3}\frac{h^2}{d}\right)$

$$= a\left\{\frac{(d - \frac{1}{2}h)^2}{d} + \frac{h^2}{12d}\right\} \qquad (55)$$

$$= a\frac{(d - \frac{1}{2}h)^2}{d} \text{ nearly.} \qquad (56)$$

Fig. 31



In a similar way we find for the triangle

$$abc,\ M = a\left(d - \tfrac{2}{3}h + \frac{h^2}{6d}\right) \qquad (57)$$

and for the triangle abc

$$M = a\left(d - \tfrac{4}{3}h + \frac{h^2}{2d}\right) \qquad (58)$$

in which a = the area of the triangle.

From (55) we have the moment of inertia of a rectangle about an axis outside of the section, as shown in Fig. 27,

$$= I = ad\left(d - h + \frac{h^2}{3d}\right) = a\left\{(d - \tfrac{1}{2}h)^2 + \frac{h^2}{12}\right\}$$

$$= a\left\{g^2 + \frac{h^2}{12}\right\} = ar^2 \text{ say} \qquad (59)$$

in which $g = d_1 + \frac{1}{2}h$ = the distance from

the neutral axis to the center of gravity of the section.

r is called the radius of gyration, and expresses the distance from the axis to a point, at which, could the whole area of the rectangle be placed, the moment of inertia would not be changed.

Dividing by a and extracting the square root of (59), to two terms, gives

$$v=g+\frac{h^2}{24g} \qquad (60)$$

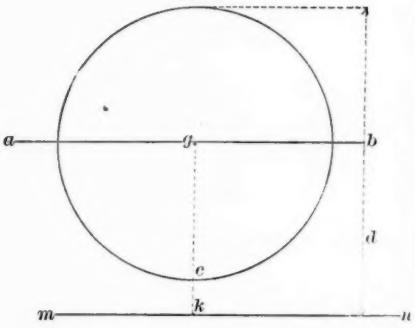
If the axis passes through the center, $g=o$, and (55) gives

$$r=\frac{h}{\sqrt{12}}=.289\,h \qquad (61)$$

If the axis passes through one edge $g=\frac{h}{2}$ and

$$r=\frac{h}{\sqrt{3}}.577\,h \qquad (62)$$

Fig. 32



FORMULAS OF REDUCTION.

To find a general expression for the moments of inertia, I, and of resistance M_1, about any axis.

Let y=distance of any element from the axis.

y_0=the distance of any element from the parallel axis through the center of gravity, and h the distance between the axes.

Let I_0=the moment of inertia about the axis through the center of gravity. Let the elementary area be represented by dA, A being the area of the section.

Now $\qquad I_0=\int y_0^2 dA,$ and

$$I=\int y^2 dA=\int(y_0-h)^2 dA=\int y_0^2 dA - \int 2hy_0 dA+\int h^2 dA=I_0+h^2A \qquad (63)$$

Since $\int y_0 dA$, which expresses the sum of the products of all the elements of area into their distances from the axis, is equal to zero.

Again, let d_0= the distance of the farthest element from the axis through the center of gravity, and d the similar distance from the parallel axis. Let M_0 and M_1 represent the moments of resistances about the axis through the center of gravity and the parallel axis.

Now $I=md$ and $I_0=M_0d_0$.

Hence from (63)

$$Md=M_0d_0+Ah^2 \text{ or } M=M_0d_0+\frac{Ah^2}{d} \qquad (64)$$

(64) is the formula of reduction for the moments of resistances.

To find the moment of resistance of a circle about any axis mn.

Let r= radius, a= the area of the circle and g, d_1 and d as before.

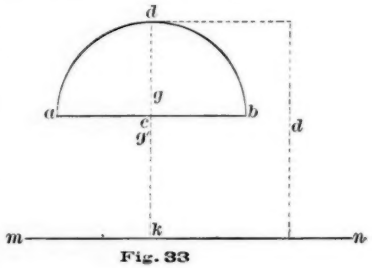


Fig. 33

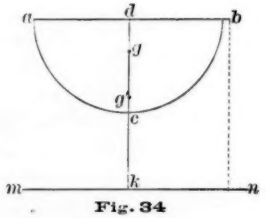


Fig. 34

Let I_0= the moment of inertia about ab and I= the moment of inertia about mn.

Now $\qquad I_0=\frac{1}{4}\pi r^4=\frac{1}{4}ar^2.$

$$I=I_0+ag^2=a[(d-r)^2+\frac{r^2}{4}]$$
$$=a(d^2-2dr+\tfrac{5}{4}r^2)$$

$$\therefore\ m=\frac{I}{d}=a\left(d-2r+\frac{5r^2}{4d}\right)=a\left(d_1+\frac{5r^2}{4d}\right) \qquad (65)$$

Putting $2r=h$, (65) becomes

$$M=a\left(d-h+\tfrac{5}{16}\frac{h^2}{d}\right)=a\left(d_1+\tfrac{5}{16}\frac{h^2}{d}\right) \quad (66)$$

To find the moment of resistance of an ellipse about any axis, parallel to a diameter of the ellipse.

Let $2b$ and $2r$ represent the axes, $r\gtrless b$, and suppose r perpendicular to the axis of moments. Then, in the same way as for the circle we deduce

$$m=a\left(d-2r+\tfrac{5}{4}\frac{r^2}{d}\right)=a\left(d_1+\tfrac{5}{4}\frac{r^2}{d}\right)$$
$$=a\left(d_1+\tfrac{5}{16}\frac{h^2}{d}\right) \quad (67)$$

This shows that the center of moments of an ellipse is the same as of a circle whose diameter coincides with the axis of the ellipse, which is perpendicular to the axis of moments.

A semi-circle (Fig. 33).

Let r=radius, a=area, and let g be the center of gravity.

Let I, I_1 and I_0 represent the moments of inertia about mn, ab and an axis through g parallel to ab or mn.

From Mechanics we have $cg=.424r$

Now $I_1=\frac{\pi}{8}r^4$

$$\therefore I_0=\frac{\pi}{8}r^4-\frac{\pi}{2}r^2cg^{-2}=\frac{\pi}{8}r^4-.09\pi r^4$$
$$=.035\pi r^4=.11r^4 \text{ very nearly.}$$

Hence

$$I=.035\pi r^4+\frac{\pi}{2}r^2\times gk^{-2}=.035\pi r^4+$$
$$\frac{\pi}{2}r^2(d-.576r)^2=.20\pi r^4+\frac{\pi}{2}r^2(d^2-1.15dr)$$

Therefore $$M=\frac{\pi}{2}r^3\left(.40\frac{r^3}{d}+d-1.15r\right)$$
$$=a\left(d-1.15r+\frac{2r^3}{5d}\right) \quad (68)$$

Putting $h=2dg=dg'=1.15r$, this becomes, $$m=a\left(d-h+\frac{3}{10}h^2\right) \quad (69)$$

A semicircle Fig. 34.

We have $I_0=.035\pi r^4$

and $$I=.035\pi r^4+\frac{\pi}{2}r^2gk^{-2}$$

$$=.035\pi r^4+\frac{\pi}{2}r^2(d-.424r)^2$$

$$=\frac{\pi r^4}{8}+\frac{\pi}{2}r^2(d^2-.848dr)$$

$$\therefore m=\frac{\pi}{2}r^3\left(d-.848r+\frac{r^2}{4d}\right) \quad (70)$$

Putting $h=2dg=dg'=.848r$ we have

$$m=a\left(d-h+\frac{1.04h^2}{3d}\right) \quad (71)$$

Thus we see that for the same values of d and h, (or of d and g, since $g=d-\frac{1}{2}h$) the lever arms of all these sections are very nearly the same, since the terms

$$\tfrac{1}{3}\frac{h_2}{d}, \tfrac{5}{16}\frac{h_2}{d}, \tfrac{2}{5}\frac{h_2}{d} \text{ etc.}$$

are approximately the same

We observe, too, that since the terms are quite small, the lever arm is in all cases, approximately, as much less than the distance to center of gravity of the section as this distance is less than the distance to the farthest fiber of the section.

From (55), $M_1-ad_1=\frac{ah^2}{3d}$, or $m-a\left(g-\frac{h}{2}\right)$

$$=a\frac{h^2}{3d} \text{ or } ag-m_1=a\left(\frac{h}{2}-\frac{h^2}{3d}\right)$$

But m_1-ad_1=the difference between ad_1 and the true moment m_1, or the error of ad_1 and $ag-m_1$ shows the errror of ag.

Now $$\frac{ag-m_1}{m_1-ad_1}=\left(\tfrac{1}{2}-\frac{h}{3d}\right)\div\frac{h}{3d}=\frac{3d}{2h}-1 \quad (72)$$

Since d is usually several times larger than h, (72) shows that ag differs from the true moment several times as much as ad_1 differs; yet ag is the value generally taken for m_1, instead of the equally simple and more accurate value ad_1.

It is plain that if each unit of area was strained equal to unity, the total strain would be equal to the area a, and the moment of strain would be equal to ag; but the outermost fibers only are so strained, and as the strain decreases uniformly toward the axis, the total strain is consequently much less than a (though the lever arm is indeed a little greater than g) and the moment of strain, or resistance, is much less than ag, as we have shown.

We may suppose, however, the strain equal to the area, which is *greater* than the real strain, provided we use a lever arm correspondingly *less* than the real

lever arm. This is what the equations do, and they may be so interpreted and understood. The lever arm, by which the area is multiplied, may be called the reduced lever arm.

The important and practical principle to be remembered is this: that the lever arm of the moment extends from the axis to a point quite as far inside of the center of gravity as the center of gravity is inside of the outermost fiber.

ENGINEERING NOTES.

ON THE INFLUENCE OF THE ADDITION OF VARIOUS PULVERIZED SUBSTANCES TO PORTLAND CEMENT—BY DR. BÖHME—Three series of researches were undertaken A. Researches with a pure cement, and its mortar formed with two kinds of sand mixed with seven different substances. B. Researches with cement mortars of thirty-nine different cements, with and without an addition of slag. C. Researches with cement mortars with an addition of slag and gypsum.

A. A Portland cement of average quality having been selected, it was tested for tension and compression, as pure cement, as mortar of one part cement, three parts standard sand, and as mortar of one part pure cement, three parts Berlin sand. Tests were made at seven, twenty-eight, ninety, and three hundred and sixty-five days. Corresponding tests were made with neat cement and cement-mortar briquettes in which 10, 20, or 50 per cent. of the cement was replaced by the following substances: (1) finest cement; (2) finest sand; (3) Duisburg slag; (4) Upper Silesian slag; (5) trass; (6) brick powder; (7) limestone powder.

The addition of (1) diminished the tensile strength of pure cement, but increased that of the cement mortars. For all the other additions the tenacity both of cement and cement-mortars is diminished.

As to the compression tests, the cubes of pure cement and pure cement with the additions give results similar to those for tension. But the strength of the cubes of cement-mortar with the additions is sometimes equal and sometimes greater than that of those without the additions.

B. To try if the same conclusion would hold good with other cements, thirty-nine German cements were selected and tested as pure standard cement-mortar without additional material, and also with an addition of 20 per cent. of Duisburg slag. Of these, twenty-nine cements showed the greater tensile strength in all stages of hardening when without any additional material. The cements with 20 per cent. addition of slag lost nearly that proportion of strength.

C. Two cements were tried in the following ways: (α) 100 parts cement, 300 parts standard sand; (β) 90 parts cement, 10 parts slag, 300 parts sand; (γ) 90 parts cement, 8 parts slag, 2 parts gypsum, 300 parts sand. In all stages of hardening β was weaker than α; but at twenty-eight days γ was about as strong as α, and at ninety days it was stronger. The increased strength, however, is known to be obtained at the cost of trustworthiness—*Abstracts of the Institution of Civil Engineers.*

THE WATER-SUPPLY OF ANTWERP DURING THE SUMMER OF 1885—The long continued drought of the summer of 1885, and the sudden increase in the consumption of water caused by the International Exhibition, had the effect of preventing the purifying-apparatus from completely destroying the marshy taste and smell which characterizes the water of the Nethe.

The dread of cholera, which at that time was ravaging Spain, rendered the inhabitants of Antwerp anxious as to the wholesomeness of the water-supply, and caused the Town Council to appoint a commission of five chemists, with Mr. C. Angenot, chemist to the city of Antwerp at their head, to institute a searching investigation into the whole subject.

The report, which was published on the 30th November, treats successively of the choice of a source of supply, of the quality of the waters of the Nethe, of the process of purification and its theory, of the general arrangement of the works, of the quality of the water furnished during the dry season of last summer, of the cause of the marshy taste and smell, of the present quality of the water-supply, and finally, of the examination of the water with reference to microbes and bacteria.

The general conclusions arrived at are, that the water supplied by the water company was never unwholesome, that the cause of the taste and smell, which only lasted for a short time, was the exceptional demand for water coinciding with an abnormally bad condition of the river caused by the prolonged drought, and that all doubts of the efficacy of the purification of water by means of iron applied through the instrumentality of the revolving purifers must fall before the researches of the English scientific men who have investigated the subject, and before the labors of the commission which has confirmed their conclusions to the fullest extent

A further report is promised, in which the investigations into the microbe and bacterial life will be more fully discussed—*Abstracts of the Institution of Civil Engineers.*

THE DESTRUCTIVE ACTION OF CEMENT-MORTAR UPON LEAD PIPING—BY OTTO PESCHKE, of Berlin—Owing to a communication from an engineer at Hanover, the author forwarded a sample of lead pipe, which had served for about six years as the supply-pipe to a fountain basin, to Dr. v. Knorre at the chemical laboratory of the Berlin Polytechnic for analysis. This pipe, throughout the portion of its length which was imbedded in the cement, was powerfully corroded; the corrosion being most marked at the end of the pipe next the basin, and the effect diminishing as the pipe receded from the water. The pipe was coated with a chocolate-colored layer of oxide of lead, of the hardness of glass, which adhered strongly to the metal. A portion of the brownish mass, at that part where it was the thickest, was detached from the pipe, pounded in an agate mortar, dried at 110° Centigrade, and

submitted to chemical analysis. It contained 99.05 parts of oxide of lead, the residue consisting of carbonic acid, with traces of lime and silica, which latter may have been due to small quantities of cement adhering to the outer surface of the pipe Dry Portland and Roman cements have been found by the author to have no action upon lead, but the presence of water appears necessary to effect corrosion. The author invites the attention of engineers and chemists to this action, which is difficult to explain, and which may be due to certain phenomena in connection with the induration of cement mortar which are at present extremely obscure—*Gesundh-its-Ingenieur.*

THE ASPHALT PAVEMENTS OF BERLIN—BY LÉON MALO—In 1876, when the maintenance of the public ways of Berlin passed from the hands of the State into those of the local authorities, there were in that city, 4,476,000 square yards of way; of which 14,400 square yards were of stone pavement laid on sand, in good condition, with 4,018 yards of the same in bad condition; 432 000 yards of macadam, and 12,000 yards of asphalt. At present there are 450,000 square yards of stone pavement laid on a solid foundation, and jointed with sand and bitumen; 654,000 yards of pavement laid on gravel, in quiet streets, in good condition; 3,705,600 yards of pavement in bad condition, temporarily laid, 579,600 yards of macadam, principally in outlying quarters, and in the Zoological Gardens; 384,000 yards of asphalt, and 48,000 yards of wood pavement

Ordinary stone pavements are laid in Swedish granite (Karlskrona), except some thousands of yards laid in porphyry from Belgium. The blocks are delivered ready for laying, the granites being from 7½ inches to 8 inches in thickness; and the porphyries from 6 inches to 6½ inches thick. According to the usual method of laying, a 4-inch layer of broken granite is deposited on the sub-soil, and upon this a second bed of granite more finely divided, also 4 inches thick, which is rolled down under a 15-ton steam-roller. A layer of gravel, about 1 inch thick, is scattered over the rolled bed, on which paving stones or sets are placed half an inch clear of each other; jointed in the intervals with a mixture of pitch and creosote. Under the lines of tramway, whatever may be the superstructure, a foundation of cement-concrete is made. Paving consisting of stone-sets laid on concrete is not in favor in Berlin.

Wood pavement, of Swedish fir, was first tried on a large scale in Berlin in 1879, laid by the Improved Wood Pavement Company. It has since disappeared, probably for the same reason that the pavement laid in Paris by the same company was removed after having been down for five years. Though this pavement was laid on a thick bed of cement-concrete, in a street of light traffic, near the Opera, the wood decayed, it wore very unequally, and was converted into mire. Carriages ceased to use the street, in order to avoid excessive jolting. Wood pavements laid by other companies still exist, to the extent of 48,000 square yards, in Berlin; but it is very unpopular, in consequence of the odor of the melted tar which escapes from the joints in summer, and its removal is but a question of time.

Asphalt pavement is extensively laid in Berlin, 384,000 square yards being covered with it, and it is destined to supersede other pavements in all the best streets of that capital. Four different asphalts are used, Val-de-Travers, Seyssel, Ragusa (Sicily), and Limmer (Hanover). The Val-de-Travers asphalt, the first that was laid, tends to become softened in the height of summer under the wheels of carriages, and to form waves, which nevertheless disappear on the return of cooler weather. In Paris, a mixture of Seyssel asphalt with that of the Val-de-Travers is found to resist that tendency. Ragusa asphalt is open to the same objection; but the Seyssel asphalt, holding a less percentage of bitumen in its composition, is entirely free from softening. It is more difficult to manipulate than the two others, and requires to be very regularly heated for laying; but it is harder and much more durable than these. The concrete foundation, which is from 8 inches to 9 inches in thickness, is laid with extreme care. It is made with an allowance of about 290 lbs. of best Portland cement for each cubic yard of "ballast," procured in the neighborhood of Berlin, consisting of flint stones mixed with a kind of corse sand. The asphalt is never laid until the concrete is perfectly set and completely dry—a precaution of prime importance for obviating the formation of steam and the consequent degradation of the asphalt, heated as it is to upwards of 250° Fahrenheit, which takes place when that precaution is not observed, as has been noticed in the earlier attempts of the Parisians in laying asphalt pavements—*Abstract from the Institution of Civil Engineers.*

IRON AND STEEL NOTES.

TINNED IRON—A writer in *Industries* makes the following observations upon the subject of the regeneration of tinned iron. After describing the precautions necessary in the acid process, he proceeds:—"Persons in the trade say that the metal is injured by absorption of the acid, and affirm that occasionally it is necessary to repeat the annealing in order to remove rottenness engendered in this manner. To the writer it appears more probable that the effect is due to occlusion of hydrogen, for the iron can scarcely be porous enough to absorb the liquid, while the power of occluding gases is a well known property of iron and some other metals. If a piece of sheet iron be immersed for some time in hydrochloric (muriatic) acid, and then be well rinsed in a stream of water for half a minute, and the acid thus removed from the surface, careful observation will reveal an interesting phenomenon. For some time after the washing, minute bubles may be seen bursting through the film of water left upon the iron, and the sound of effervescence may be heard if the metal be held near the ear. This is probably due, not to any evolution of hydrogen by acid, since this has been removed by washing, but to the escape of hydrogen from the pores of the iron. Producers of wrought iron say that the scrap stripped by acid always makes

inferior iron if mixed in any considerable proportion with new metal. Yet this tin plate is rolled originally from good iron, and can be made so again if suitably treated. The reason, doubtless, is to be sought, not in the imperfect removal of tin, as often stated, but in the occlusion of hydrogen gas." If this view be correct it is probable that the hydrogen could most speedily be removed in an electrolytic bath, containing a suitable oxidising agent in which the iron was made the positive electrode.

ON A PECULIAR ACTION IN STEEL PROPELLER SHAFTS—At a recent meeting of the Institution of Engineers and Shipbuilders in Scotland, Mr. Thomas Davison directed the attention of the members to what he considered a peculiar form of corrosion in propeller shafts. He distinguished it from the ordinary form of corrosion, which has long been observed to take place at the ends of the covering brasses of propeller shafts, and which frequently causes a groove so deep as to render them unfit for use. He gave it the name of "radial corrosion," as it resembles a crack round the shaft extending towards the center, the corroded part usually having a radiated crystalline appearance quite different, in his opinion, from any fracture produced by mechanical force. Having in the course of his experience met with many failures of iron shafts, he was induced, from not having had a single case of failure in the use of steel, in steel ships, steel boilers, steel shafting, piston rods, and other parts of engines, to advise the use of steel shafts made from one ingot, so as to avoid the flaws and imperfections inseparable from iron shafts made of many pieces welded together. He was disappointed, however, to find that this special kind of corrosion of which he spoke, interfered with the use of steel in propeller shafts, and in some cases they were so rapidly corroded that the steel shafts had to be replaced by iron ones until he had time to test the causes of the failure.

As some of his friends did not agree with Mr. Davidson in thinking that the flaws in the shafts were caused by corrosion, he wished to give his reasons for his opinion. The shafts which had failed were all of the usual size of iron shafts; their material, as tested by Kirkaldy, was found to have an elastic limit and ultimate strength of over forty per cent. more than iron; and when tested after corrosion were found not to have deteriorated. Moreover, it was found that of two shafts exactly similar, one corroded and the other remained perfectly sound, and he inferred that the one was water-tight and the other was not. He illustrated the flaws by many drawings and spicimens from shafts, and concluded by urging on engineers the necessity for paying special attention to the subject, so that a remedy might be found for what seems to be the only objection to the use of steel for propeller shafts.

In the discussion which followed the reading of the paper, opinion was divided on the subject, some agreeing with Mr. Davison that the failure of the shafts was caused by corrosion, others thinking it was caused by the want of stiffness in the steel. The propellers being overhung, their weight and also their reaction would cause a continual bending and unbending, which, combined with rotation, would rapidly produce the action described by Mr. Davison. Mr. Dick, of the Steel Company of Scotland, had conducted some experiments with rotating pieces of steel subjected to bending action, and he had found that fractures very similar to those described by Mr Davison were produced. We will not pronounce an opinion on the subject; but as it is one of considerable importance both to steel makers and marine engineers, we will be glad to have the opinions of a few correspondents, that thus we may assist in the attainment of the object Mr. Davison had in view when preparing his paper —that is, the determination of the real causes of the flaws in the shafts.—*Industries.*

RAILWAY NOTES.

NOTES ON THE PERMANENT WAY OF LIGHT RAILWAYS—BY J. W. POST, Engineer to the Netherlands State Railways Company—The first concession for light railways on the 1.5 meter gauge, given under the law of 9th August, 1878, by the Dutch Government, was to the Geldersche-Overysselsche Company, for lines of a total length of 135 kilometers. The author describes the system of permanent way adopted for this railway, constructed under his superintendence. At present steel rails and red pine sleepers, 1 meter apart, are used, but it is intended to replace the wooden by metallic sleepers. The rails are of the Vignoles type: height, 120 millimeters; width of bottom flange, 90 millimeters; sectional area, 32.6 square centimeters; and weight, 25.6 kilograms per meter length. The standard length of rail is 9 meters. The price paid for rails between 1882 and 1887 was 70.62 florins per ton of 1,000 kilograms, or £5 8*s.* 6*d.* The fishplates are steel, the outside plate with an angle bent outwards, to stiffen the joint, rests on two sleepers. To prevent the rails from creeping, a dogspike is driven at each end against this flange.

The same price per ton was paid for the fishplates as for the rails. Grover spring-washers, of cast steel, are used wtih all bolts. These only cost 11 florins per thousand. The total weight of metal per lineal meter of permanent way is 55.6 kilograms. At the points the rails are placed vertical; the outer rails are not lifted in the curves. The maximum widening of guage in the curves is of 20 millimeters. The angle of crossing is 1 in 9 in all cases, and the total length of a set of points and crossings is 24.01 meters. The points can therefore be laid on the existing tract without cutting up the rails. The switches are shaped to a curve of 180 meters radius, and only 7.50 meters long, and carefully planed to exact shape. No part is longer than 6 meters, to facilitate carriage. The crossings are of a total length of 2.16 meters, and joined to the rails at each end by straight fishplates. The packing-pieces between abutting rails are specially cast for each end. The grooves are 44 millimeters wide, and 42.5 millimeters deep. The check-rails are 3 meters long. The points and crossings are laid on oak sleepers of 14 by 25 centimeters,

and 55 centimeters apart. The cost per kilometer of permanent way, without ballast or laying, is 6,000 florins, and that for a complete set of points and crossings is 575 florins. The paper is accompanied by several addenda and drawings.—*Abstracts of the Institution of Civil Engineers.*

RAILWAYS OF EUROPE IN 1884.—The total length of railways opened for traffic at the end of the year 1883 amounted to 113,716 miles. At the end of 1884 the length open was 117,653 miles, showing an increase of 3,937 miles opened in the course of 1884, or 3.46 per cent. of the total length at the end of 1883. The following table shows the length of railways open, in each European State, at the end of 1884:

Railways of Europe 1884.

Designation of State.	Length of Railways open for Traffic at the end of 1884.	Increase per cent. in 1884, above the length of open at the end of 1883.
	Miles.	Per cent
1. Germany	22,830	2.31
2. Austria-Hungary	13,736	5.99
3. Belgium	2,684	1.08
4. Denmark	1,208	7.23
5. Spain	5,383	4.99
6. France	19,397	5.05
7. Great Britain and Ireland	18,962	1.11
8. Greece	109	695.45
9. Italy	6,167	4.97
10. Low Countries and Luxemburg	1,649	5.28
11. Portugal	949	2 21
12. Roumania	995	5.39
13. Russia and Finland	15,778	2.02
14. Servia	152	....
15. Sweden and Norway	5,072	2.54
16. Switzerland	1,716	0.40
17. Turkey, Bulgaria, and Roumelia	866	....
Total	117,653	3 46

Of the total increase of length of railway opened in the course of 1884—namely, 3,937 miles—515 miles were opened in Germany, 776 miles in Austria-Hungary, 256 miles in Spain, 933 miles in France, 208 miles in Great Britain and Ireland, 292 miles in Italy, 313 miles in Russia and Finland, 152 miles in Servia, and 125 miles in Sweden and Norway.—*Abstracts of the Institution of Civil Engineers.*

THE TRANSCASPIAN RAILWAY.—A correspondent writing from Askabad to the *Rus-ki Viedomost* (Russian Gazette) says:—"The construction of the Transcaspian Railway is progressing rapidly towards completion. The embankment is nearly ready all the way to Merv, and the rails are already laid down to Kaakhee, a point about 30 versts distant from the future station of Dooshck, so that everything is ready for opening 560 versts of line. The carriage of material and the means for its transport are both on an extensive scale, and it is hoped that circulation will be possible up to Merv from June 1. At the present moment great activity is being shown in the construction of the bridge over the river Tendghen, which work has been partially delayed through the peculiarly unfavorable nature of the ground forming the bed of the river, in consequence of which it has been necessary to sink into it five rows of cast-iron piles, each pile being 63 feet in length. At Askabad itself, the future centre of the Transcaspian railway system, the buildings in connection with the railway are rapidly rising.

ORDNANCE AND NAVAL.

IN March the obsolete French armor-clad Armide was towed to sea in the Juan Gulf and allowed to drift. The Colbert, Admiral Duperré, Friedland, Dévastation, Redoubtable, and Suffren, of the French Mediterranean squadron, then steamed about, firing at her at ranges of 3000, 4000, and 5000 meters, with 24, 27, and 32 centimeter guns—roughly 9½in., 11in., and 12in. In time the hull resembled a cullender. Three shots had passed through the armor at the water-line, and would have sunk the ship if she had not been filled with casks. The Armide was then towed into harbor, and the effects of the fire carefully inquired into. This probably is the first occasion in which an armor-clad has been used as a moving target by ships firing when under way.

RUSSIAN IRONCLADS—A St. Petersburg correspondent writes respecting the recent launching of two Russian ironclads by the Czar: "It is interesting to note the great progress made by the Russian Navy during the last three years, no less than twenty-seven vessels of various kinds—exclusive of torpedo-boats—including the two just launched, the Tschesme and Catherine II., having been added to it, whilst several more are on the stocks, among which the great ironclads Sinope, sister ship to the Tschesme, and Imperator Alexander II., and Admiral Nachimoff. There are besides, building, three formidable first-class gunboats, in Sweden, Norway, and Denmark, which are to be delivered this year, whilst it is the intention of the Government to lay down the keel for several others in the Black and Siberian Seas. Great improvements are also being made in the two naval stations, Cronstadt and Sebastopol. In the former place granite quays and breakwaters are being constructed, whilst at Sebastopol the two naval docks recently inspected by the Czar, and which were destroyed in the Crimean War, are so far completed that they will be opened for use this year. The cost of each of these will be £300,000, and the Russian Admiralty states that they are the first undertaking of the kind in which the actual cost has not exceeded the estimate. The plan which has been before the Admiralty some time, of making Libau a naval port, has

been abandoned, but it has been decided to make it the station of the Baltic fleet. In connection with the name, it may also be mentioned that the Obrichoff Steel-plate Works and the Ishorscic iron-plate foundries have recently been improved and enlarged."

Some important additions will shortly be made to the Swedish Navy by the completion of the first-class torpedo boat Galdr and the first-class gunboat Svea. The former was built at the Royal Dockyard, on the same lines as the torpedo boat Sejd, which was constructed by Messrs. Thorneycroft some years ago, and is stated to be quite equal to the latter in solidity and speed, although considerably cheaper. The length of the vessel is 103ft.; breadth, 11½ft.; whilst she draws only 5ft. of water. The engines, which give her a speed of 20 to 21 knots per hour, are of 425 indicated horse-power. The total cost is £6,000. She will carry light guns, and be armed with Whitehead torpedos. The other vessel—the Svea—is being built at the Lindholmen Engineering Works, at Gothenburg. She will be one of the most formidable vessels in the Swedish Navy, carrying her guns in a turret. She will also be armed with torpedos. Some of the heaviest plates used in the construction of this vessel are from Le Creusot; the rest from Motala. Her engines will be very powerful. In Norway progress is being made in the Royal Dockyards with the building of two first-class torpedo boats and two gunboats of the second-class. A proposal is also being made to build an ironclad of modern type, which would be the first possessed by that country, excepting monitors. In Denmark the Government have decided upon two important additions to the navy, in the shape of an ironclad of the second-class, to be named the Valkyrien, which will be heavily armed, and cost about £160,000, and a fast cruiser of the first-class, costing about £150,000. During the present year an important addition will be made to the navy by the launch of the double-turret ironclad Ivar Hvitfeldts, carrying very heavy ordnance, which has taken three years to construct.

BOOK NOTICES

PUBLICATIONS RECEIVED.

Papers of the Institution of Civil Engineers. No. 1942. The Separation of Galena and Blende. By Ernest DuBois Lukis, Assoc. M. Inst. C. E

No. 2108. Construction in Earthquake Countries. By John Milne, F. G. S.

No. 2110. Design and Stability of Masonry Dams. By William Bulkeley Coventry, M. Inst. C. E.

No. 2158. Modern Machine Tools. By William Wilson Hulse, M. Inst. C. E.

No. 2168. —— Footpaths. By Henry Percy Boulnois, M. Inst. C. E.

No. 2169. The Effects of Various Liquids on Iron. By David Phillips, M. Inst. C. E.

No. 2171. Coefficients of Discharge in Submerged Weirs of Large Dimensions. By Robert Hunter Rhind, M. Inst C. E.

No. 2176. A Circular Chimney Shaft. By John Markworth Wood, Assoc. M. Inst. C. E.

No. 2181. Maintenance of the Belah and Deepdale Viaducts. By William John Cudworth, Assoc. M. Inst. C. E.

A Method of Designing Screw-Propellers. By Christian Hoeple. Philadelphia: Franklin Institute.

Bulletins of the U. S. Geological Survey. Washington: Government Printing Office.

No. 27 Work Done, the Division of Chemistry and Physics.

No. 28. The Gabbros and Associated Hornblende Rocks occurring near Baltimore, Md.

No. 29. On the Fresh Water Invertebrates of the North American Jurassic.

Pilot Charts of North Atlantic Ocean for August and September. Washington: Hydrographic Office.

Monthly Weather Review for July. Washington: Signal Office.

Directory to the Iron and Steel Works of the United States. Philadelphia: American Iron and Steel Association.

Hand-Book of Mineralogy. Determination, Description and Classification of Minerals found in the United States. Science Series No. 86. By J. C. Foye, A.M., Ph.D. New York: D Van Nostrand. Price, 50 cents.

This author's "Mineral Tables" have been known to mineralogists, and have been found so useful that two editions have become exhausted. The material of the old editions is still retained, but important additions have been made in constructing the present book.

The descriptions of the minerals are in this book expanded into paragraphs, and the work is now as complete a manual of determinative mineralogy as can be found in a pocket-book.

Traité Pratique d'Électricité. Par C. M. Gariel. Second volume. Paris: Octave Doin.

This general treatise upon the applications of Electricity aims to give the reader the entire subject to the latest development.

This new volume deals with late telephonic and telegraphic systems and with indicators, registers and regulators.

The total number of illustrations in the two volumes is 600.

The Surveyor's Guide and Pocket Table-Book. By B. F. Dorr. New York: D. Van Nostrand.

This little book contains much that is needed by land surveyors, and that is not contained in other books bearing similar titles.

Rules for the guidance of beginners are clearly given, and as given by the author have the approval of the Commissioner of the General Land Office.

The hints in relation to local attraction are especially valuable.

The book is of convenient size for the pocket and contains tables of natural sines and tangents to five minutes and a traverse-table to quarter degrees.

PRACTICAL PERSPECTIVE. By ARMAND CASSAGNE. Translated by G. MURRAY WILSON. Paris: A. Fourant.

This is a thoroughly scientific treatise on Perspective, although it requires but a moderate amount of geometry to comprehend it. Unlike other works which afford the same amount of geometrical demonstration, this one is adapted to needs of the artist and of architects' draughtsmen. Shades, shadows and water reflections receive special and full treatment.

The illustrations are numerous but not very good.

TREATISE ON THE THEORY OF THE CONSTRUCTION OF HELICOIDAL OBLIQUE ARCHES. By JOHN L CULLEY, C.E. Science Series No. 87. New York: D. Van Nostrand. Price, 50 cts.

The construction of an oblique arch, even of moderate span, requires a kind of skill that is not demanded in arches of the more common or straight type. The problem is considered a somewhat difficult one.

The solution offered by Mr. Culley is easily comprehended. He says in his preface that he is satisfied that much of the confusion and misunderstanding about the subject have arisen from the fact that authors have failed in presenting the fundamental principles, and he declares that the proper conception of the process of generating helicoidal surfaces will clear away all difficulties.

Chapter I. is devoted to the elucidation of the principle of construction of such surfaces.

The construction is certainly clearly described and is illustrated with excellent figures.

The subject is interesting, especially to engineers, whether they engage in practical problems of this nature or not.

THEORY OF MAGNETIC MEASUREMENTS, WITH AN APPENDIX ON THE METHOD OF LEAST SQUARES. By FRANCIS E. NIPHER, A. M. New York: D. Van Nostrand. Price, $1.00.

Magnetic surveys are peculiar in their character. A special training is required to fit the surveyor for his work, and the few who acquire expertness have been heretofore regarded as a class of scientists who had drifted into their work through some fortuitous circumstances or capabilities rather than engaged in it after a systematic course of training

Electrical and magnetic measurements have of late assumed a new importance, and knowledge of the principles involved is eagerly demanded.

The writer gives such hints and instructions to learners as have been suggested by his own experiences in such surveys.

ANALYSE ELECTROLYTIQUE QUANTITATIVE. Par C. BLAS. Paris: Georges Carre.

The electrolytic method of analysis is based on the decomposition by the electric current of compounds in solution, and the formation of deposits on the electrodes.

It possesses the merit of great simplicity, and it requires less supervision than the chemical method. It has been much practiced of late years, and is being constantly extended to embrace a larger number of compounds.

This work is divided into two parts. The first part treats: 1st, of the apparatus required; 2d, of the electrolytic characters of the metals; and 3d, of the separation of the metals one from the other.

The second part treats of the analysis of minerals and metallurgical products.

Forty-two wood cuts embellish the work.

REPORT ON EUROPEAN DOCK-YARDS. By Naval Constructor PHILIP HICHBORN. Washington: Government Printing Office.

This report gives the results of a tour of observation among the dock-yards of England, Scotland, France and Germany.

The ship-yard appliances and tools receive much attention, and are fully illustrated.

Many plans on large scales of ships and ship-yards embellish the reports.

GEOLOGICAL SURVEY OF NEW JERSEY. Annual Report of the State Geologist for 1885. Trenton: John L. Murphy.

The State Geologist arranges his report under five different heads, viz.:

I. The Geographic including Geodetic and Topographic Surveys.

II. Geological, including Structural and Lithological Geology.

III. Economic Geology, including Mining, Quarrying, Water Supply, Drainage, Agriculture and Forestry.

IV. History of the Geological Surveys of the State and Industrial Interests during their Progress.

V. Miscellaneous Papers.

This report shows, as do the preceding ones, that the work done year by year is with special reference to developing and making known the mineral, agricultural and hydrographic resources of the State. It is a good model for geologists in other States

THE TECHNO-CHEMICAL RECEIPT BOOK.—Containing several thousand Receipts covering the Latest, Most Important, and Most Useful Discoveries in Chemical Technology, and their Practical Application in the Arts and the Industries Edited chiefly from the German of Drs. Winckler, Elsner, Heintze, Mierzinski, Jacobsen, Koller, and Heinzerling, with additions by William T Brannt, Graduate of the Royal Agricultural College of Eldena, Prussia, and William H. Wahl, Ph. D. (Heid), Secretary of the Franklin Institute, Philadelphia. Illustrated by 78 engravings. 496 pp. 12mo. Henry Cary Baird & Co. Price, $2.00.

In this book we have the gleanings of the latest scientific and technecal papers of Germany, carefully edited, with numerous and valuable American additions by Dr. Wahl, whose reputation as a painstaking and careful editor at once gives the work an established place among manuals of this character. It is impossible to give any detailed description of the subjects treated for that would be a simple repetition of the table of contents. We find the information to be both accurate and reliable. It is the latest work of this character that has been published, and as such, contains much that is not elsewhere attainable. The book is supplied with a very complete index, making it possible to turn at once to any subject on which infor-

mation is desired. Numerous illustrations are contained in the text, serving to make clear the descriptions. The book is printed in clear type and on good paper. Indeed, its general make-up reflects much credit on its publishers.

THE SEPARATE SYSTEM OF SEWERAGE. By CADY STALEY AND GEO. S. PIERSON, C. E. New York: D. Van Nostrand. Price, $2.50.

There are two systems of sewerage for towns, one known as the combined and the other as the separate. The combined is that most in use, especially in large cities, its object being the carrying off the storm water as well as the sewage. In order to carry off the heavy waterfall of sudden storms the sewers have to be made very much larger than would be needed for the ordinary demand upon them, hence the cost is enormously increased. The main sewers have to be of large size and of brick, the inequalities of which arrest the impurities of the sewage flowing past and generate sewer gas in great volume. It is almost impracticable to keep them properly flushed, especially in dry seasons, whilst, as our home experience has frequently shown, in case of heavy rain-storms the sewers, large as they are, prove insufficient to carry off the surplus water, the sewers are gorged and the streets converted into lakes or beds of rushing currents. At the same time there are cases, especially in some parts of this city, where surface drainage would not carry off the storm water because of insufficent fall, hence some under-ground drainage system is here necessary.

The separate system is designed to carry off the sewage only, with sufficient water to flush and cleanse the pipes. Having to make provision for what is practically a regular supply, the engineer in determining the size of the pipes has only to take into account the probable increase of population in the district to be sewered and the consequent increased capacity required. The advantages of this system as set forth in the volume are very great, including greater convenience, lessened cost, and superior sanitary provisions. The difference in cost is illustrated in the case of the city of Schenectady, N. Y. The estimated cost of the combined system, similar in its general features to that of Cleveland, was $240,000. The separate system was finally adopted and carried into effect under the design and execution of Professor Staley and Engineer Pierson at a cost of $35,000.

Professor Staley claims for the separate system that its introduction marks an important era in the development of sanitary drainage, recognizing as no other system has the prime importance of an early removal of household and industrial wastes, which are the main factors in soil pollution. That it will best meet the requirements of all large and densely populated cities (economy considered), he does not think probable. But that, under competent advice, it can meet the requirements of house drainage more perfectly in any city than the combined system he insists cannot be denied. It is peculiarly adapted to many of the numerous smaller cities, which have been practically debarred from sewerage by its cost, and to outlying portions of larger ones. Its comparatively small cost permits an early and general extension, and the removal of domestic wastes before the soil has become saturated with them beyond a reasonable hope of purification.

In addition to chapters on sewerage in general and on the different systems of sewerage and drainage, the work contains nine other chapters giving plans of sewerage, information as to calculating the quantity of sewage, the laws of flow in sewers, materials and accessories, specification and contract, construction, flushing and ventilation, house drainage and plumbing, cost and assessments. Twenty plates of illustrations and a large folding map of Schenectady, showing the sewerage system, add to the practical value of the work —*Cleveland Paper.*

MISCELLANEOUS.

IN his lectures on Petroleum, before the Society of Arts, Mr. Boverton Redwood notes that Gibbon states that, in A. D. 624, the Emperor Heraclius wintered at the mouth of the river Kura, seventy miles south of Baku, and that his "soldiers extinguished the fire, and destroyed the temples of the Magi" Marco Polo, who wrote in the 13th century, is supposed to have referred to the petroleum of Baku when he stated that there was in this neighborhood an abundant spring of oil, not good for food, but good to burn or to anoint camels that had the mange; and he added that the people came from great distances to collect it. As far back as 1436, petroleum found on the shores of Lake Tegernsee, in Bavaria, was employed medicinally under the name of "St. Quirinus's oil." Francesco Ariosto stated that he cured men and animals afflicted with itch with the petroleum which he had discovered in 1460 at Mont Libis, in the Duchy of Modena. Jonas Hanway, in the middle of the 18th century, described the so-called eternal fire at Surakhani as a flame in color and gentleness not unlike a lamp that burns with spirit, only more pure, and sometimes rising to a height of 8ft. when the wind blows.

A USEFUL pamphlet on the "Corrosion of Iron and Steel," written by Mr. T. H. Davis, F.I.C., formerly assistant at the Royal College of Chemistry and School of Mines, London, is being published. The author says that if the air or water which surrounds iron contains carbonic acid, or any free acid in minute quantity, the corrosion increases rapidly, but if a caustic alkali, such as potash, soda, or lime be present, the corrosion ceases altogether while any causticity remains, because oxygen and carbonic acid have greater affinities for these alkalies than for iron. He also points out that a perfect paint for the protection and preservation of iron and steel should be one which has a high mechanical adhesive property, and composed of such materials that are related electro-negatively to iron, mixed with some tenacious fluid vehicle containing little or no oxygen, and not capable of being decomposed by the iron beneath it. This would exclude most oily paints.

A curious phenomenon, the *Scotsman* reports, was witnessed at Stonehaven on Sunday afternoon, May 23rd. At intervals just before and after high tide, without any apparent cause, the water along the coast rose and fell from 10in. to 18in. at a time, the subsidence leaving as much as 15ft. to 18ft. of the beach dry. The disturbance continued for three hours, commencing about half-past 4 o'clock. There was no wind, and the sea was quite smooth, but the water advanced and retired with a speed equal to the run of a large river during a spate, and caused so much commotion in the harbor that the fishermen had to secure their boats with extra moorings to prevent damage being done. Indeed, it is seldom that there is so much commotion in the harbor, even during stormy weather. It is surmised that the phenomenon was due to some eruption or subsidence in the sea bottom.

Artesian tube wells are now being fixed at the following places in London:—For the supply of the flats and offices of the Albert Hall-Mansions, South Kensington, and the Westminster chambers, Victoria street, S. W. The depth to be reached in either case to obtain the required supply will be over 400ft. Ere the chalk beds are reached, thick layers of London clay and Woolwich and Reading beds will have to be penetrated. It is only in recent years that this economical and expeditious system of obtaining large supplies of pure water from deep sources has been so perfected as to almost entirely supersede the old method of sinking dug wells. These artesian wells are protected by an even-sized tube, which is carried from the surface to the chalk beds, and it is absolutely impossible for any of the polluted springs which are found in the upper beds to contaminate the lower ones. Messrs. C. Isler & Co., of Southwark street, have the works in hand.

In their report on the water supplied to London during March, Mr. William Crookes, Dr. William Odling, and Dr. C. Meymott Tidy say: "The condition of the water supplied by the metropolitan companies during the past month was, in all respects, thoroughly satisfactory. With the absolute proportion of organic matter continuously low, not much importance can be attached to varations in its relative proportion from month to month. Still, with the advance of the season, the attendant diminution in the quantity of organic matter present in the water is, as usual, well marked. Thus, while the mean amount of organic carbon in the Thames-derived supply for January was .183 part, the mean amount for February was .172 part, and the mean amount for last month .153 part in 100,000 parts of the water, corresponding to scarcely more than a quarter of a grain per gallon of organic matter, a natural constituent of river water, which, even in larger proportions, there is not, as pointed out by the last Royal Commission on Water Supply, any reason to regard as objectionable."

The following are among the prizes offered this year by the Paris Academy of Sciences:—Geometry: A study of the surfaces admitting all the symmetrical planes of one of the regular polyhedrons—3000f.; Francœur prize, the work most conducive to the progress of the pure and applied mathematical sciences—1000f. Mechanics: Extraordinary prize of 6000f. for any work tending most to increase the efficiency of the French naval forces; Montyon—700f.—invention or improvement of instruments useful to the progress of agriculture, of the mechanical arts or sciences; Plumey—2500f.—improvement of steam engines or any other invention contributing most to the progress of steam navigation; Dalmont—3000f.—the best work by any of the Ingénieurs des Ponts et Chaussées in connection with any section of the Academy. Astronomy: Laland prize—gold medal worth 540f.—for the most interesting observation on work most conducive to the progress of astronomy; Damoiseau—10,000f.—best work on the theory of Jupiter's satellites, discussing the observations and deducing the constants contained in it, especially that which furnishes a direct determination of the velocity of light; Valz—460f.—for the most interesting astronomical observation made during the course of the year. Physics: Grand prize of the mathematical sciences—3000f. for any important improvement in the theory of the application of electricity to the transmission of force. Statistics: A prize of 5000f. for the best work on the statistics of France. Chemistry: Jecker prize—5000f.—for the work most conducive to the progress of organic chemistry. Geology: Vaillant prize, on the influence exercised on earthquakes by the geological constitution of a country by the action of water or of any other physical causes.

At a recent meeting of the Royal Society a paper was read on "The Effect of Change of Temperature on the Internal Friction and Torsional Elasticity of Metals," by Mr. Herbert Tomlinson, B.A. The vibration period and the logarithmic decrement were very carefully determined at four different temperatures between 0 deg. C. and 100 deg. C., and that the formulæ were worked out by the method of least squares. These formulæ were given in tables. From a consideration of the tables it may be gathered that: (*d*) The torsional elasticity of all metals is temporarily decreased by rise of temperature between the limits of 0 deg. C. and 100 deg. C., the amount of decrease per degree rise of temperature increasing with the temperature. To this may be added that the percentage decrease of torsional elasticity produced by a given rise of temperature is for most metals about twenty times the corresponding percentage increase of length. (*e*) If we start with a sufficiently low temperature the internal friction of all annealed metals is first temporarily decreased by rise of temperature and afterwards increased. The temperature of minimum internal friction is for most annealed metals between 0 deg. C. and 100 deg. C.; for most hard drawn wire, however, the temperature of minimum internal friction is below 0 deg. C. (*f*) The temporary change, wrought by alteration of temperature in the internal friction of metals, is in most cases enormously greater than the corresponding change in the torsional elasticity.

THE ELASTICITY OF METALS. M. TRESCA, the celebrated Parisian experimentalist, lately published in the *Comptes Rendus* the results of observations made as to the effect of hammering, and the variation of limits of elasticity as regards metals and other substances used for technical purposes. He remarks that it has hitherto been usual, in considering the deformation of solid bodies under the influence of extensile force, to recognize only two definite periods, dependent upon the mechanical properties of the substances in question. These periods are the limit of elasticity, and the point of laceration. According to his own trials, M. Tresca has found it necessary at end of the period where the change of elasticity commences, to recognize a third stage, which may be described as a period of fluidity, and which corresponds with the possibility of a continuous deformation under the constant effect of the same tension. This peculiar condition only occurs in substances of a very extensible or plastic nature, and may be regarded as a characteristic of such substances, as the absence of this condition is noticed in materials that are brittle or not extensible, and which are lacerated or fractured without previous deformation. It is already known that the period of alteration of elasticity is much shorter in hard or hardened steel than in iron.

In the year 1871, M. Tresca proved that steel and iron rails, which had undergone a permanent extension, proved completely elastic up to the limit of the burden which they had already experienced. With certain iron and steel rods the same result was obtained five times in succession, and thus the period of complete elasticity could be gradually prolonged, while the co-efficient of elasticity did not appear to suffer any notable change. By the process of repeated extension, if no hammering takes place, tough substances are rendered brittle.

M. Tresca protests against the expressing of the prolongation of metal bars produced by burdens in the form of a percentage of their length. Such prolongation is, he urges, always specially local, and consequently the same in long and short bars, being limited by the proximity of the point of fracture. The indication of elasticity should, therefore, rather be sought in the diminution of the section of the bars at the point of fracture. This portion of a lacerated bar is further remarkable for the loss of the original state of its material composition. At the point of fracture, the substance has become remarkably condensed, and has almost entirely lost its toughness. The final fracture, therefore, takes place in a brittle zone of the metal, and the same condition can be produced by hammering. If a test bar, which has been extended almost to the point of fracture, be thoroughly heated, it can be still further extended before it breaks, and it is really a fact that by alternate stretching and heating such a bar may be extremely changed in its proportions, as is, for instance, the case in wire drawing.—*Industries.*

EGYPTIAN PETROLEUM. The extensive reports that are appearing in the daily papers from their Cairo correspondents, bear out the original announcement that the petroleum supply at Jebel Zeit is of the most copious character. We have yet to learn, however, the general specific gravity of the oil, and until Mr. Tweddle and the chemists at Antwerp and London, where samples have been sent, have expressed an authoritative opinion, this very important point will remain unsettled. According to one of the earliest telegrams dispatched, the oil had a specific gravity approaching that of the heavy Burmese oil, and was capable of yielding only 8 or 10 per cent. of refined petroleum. As the American crude oil yields 75 per cent. of burning oil, and the Russian petroleum 30 per cent., this implies an inability to compete very seriously with existing oil refiners. Petroleum, however, often varies largely in specific gravity in the same district, and it might be that the original samples, and even those subsequently transmitted to Europe, did not fairly represent the general quality of Egyptian oil. But admitting that the oil is not a copious yielder of the petroleum of commerce, it has, apart from this, not only a great future before it as a lubricant and as fuel, but further may yet benefit by the improvements in lamps which are now being made, rendering them able to burn a heavier refined petroleum than that now in general use. The Defries lamp, for instance, burns successfully oil of a specific gravity of .830, which would allow of a very much larger employment of Egyptian oil for illuminating purposes than the percentage we quoted above. Doubtless this success will be followed by others in the same direction. As an enormous demand is arising for the Defries lamp, and the knowledge of the new oil which is being derived from the variety of uses to which it is being applied, will lead to further improvements. In short, now that the heavy oil regions of Russia, Burmah, and Egypt are coming to the front, the pressure of their cheap and copious supply of refined petroleum, heavier than that in possession of the market, and hitherto practically secluded from it, will impel the public to favor the new article, and this will react in turn beneficially upon Egypt and Burmah. Such a tendency deserves to be encouraged, because the heavier oils which are burnt by the Defries lamp are as safe as colza and other vegetable oils, and the risk of fire and accident is thereby reduced to a minimum. Considering that nearly every week, all the year round, an inquest is held in London on the victims of a lamp explosion, and that the development of the petroleum oil trade implies an increase of risk, it is most satisfactory that not only has the Defries lamp—which even when burning ordinary oil can be upset or blown into without fear of spilling the oil or causing an explosion—come into use precisely when wanted but by burning a safe heavy oil has further increased the immunity of the public from danger, and at the same time given additional value to the petroleum fields of Egypt.

NOTE.—The Editor respectfully calls the attention of the readers of the magazine to the advertisement on the second page of the cover of this number.